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Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region

A Decade of Experience from SERVIR

ICIMOD SERVIR HINDU KUSH HIMALAYA

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Springer

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ISBN 978-3-030-73568-5 ISBN 978-3-030-73569-2 (eBook)
https://doi.org/10.1007/978-3-030-73569-2

Cover illustration: Cover image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center. NASA Photo ID: ISS041-E-81045
Copyeditors: Samuel Thomas, Shanuj VC, Utsav Maden, Rachana Chettri, Kundan Shrestha
Graphic design: Sudip K. Maharjan, ICIMOD

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

We are in a new age of technology—as our planet's health deteriorates, we are also able to monitor and act on changes with swiftness, greater accuracy, and wider impact. The unprecedented and rapid advances in Earth observation (EO), geospatial, and digital technologies have dramatically improved our ability to understand and respond to the impacts of climate change and other human-induced threats. These technologies have become instrumental in measuring and monitoring our natural and social environments and the effectiveness of our development policies and programmes. More than ever, these technologies have great importance in the Hindu Kush Himalayan (HKH) region, which faces a range of challenges such as melting glaciers, degrading ecosystems, changing environments, globalization, and a multitude of socioeconomic pressures.

As an intergovernmental knowledge and learning centre, ICIMOD aims to serve the HKH region through information and knowledge generation and sharing to find innovative solutions to critical mountain problems, bridging science with policies and on-the-ground practices. The Mountain Environment Regional Information System (MENRIS), one of our longstanding regional programmes, has continually worked to improve access to and use of EO and geospatial information technologies and developed meaningful applications for integrated mountain development. Under MENRIS, ICIMOD has partnered with USAID and NASA to implement SERVIR Hindu Kush Himalaya (SERVIR-HKH) as a regional hub of the SERVIR Global Initiative. Over the last decade, SERVIR-HKH has worked extensively with national and international partners to develop various EO and geospatial information services in the fields of agriculture and food security, land cover and ecosystems, water resources and hydro-climatic disasters, and weather and climate. By adopting a service planning approach, SERVIR-HKH has been able to focus on the users and their capacity-building needs. Given the diversity of users in the region and the unique issues they face, addressing their needs is not without challenges. This book illustrates the range of areas, the depth of work, and the broad impact achieved by the SERVIR-HKH team and our partners. Their collective learning in the process will be beneficial to all those interested in applying these tools in the HKH region and beyond.

I would like to take this opportunity to thank the SERVIR-HKH team at ICIMOD, NASA SERVIR Science Coordination Office at the NASA Marshall Space Flight Center, principal investigators and team members of the NASA Applied Science Projects, USAID Washington and USAID Country Missions in the region, and national and international agencies who have partnered with SERVIR-HKH for their important contributions. That NASA and USAID have extended support to SERVIR-HKH for another five years is testimony to the importance of its work for the environment and communities in the region. I am confident that the current and future work of SERVIR-HKH will make significant contributions to the HKH Call to Action, which is a key priority for ICIMOD and backed by all our member countries.

Pema Gyamtsho
Director General, International
Centre for Integrated Mountain
Development (ICIMOD)
Kathmandu, Nepal

Message from USAID

The global health pandemic is a stark reminder of the importance for timely, accurate, and credible information to help governments and individuals understand and manage risk. While the challenges addressed by the SERVIR partnership are different than those of a pandemic health crisis, there is a parallel need for strong systems that integrate timely, accurate, and credible weather, climate, and land use information into decision-making processes for improved food security, water resource management, hydroclimatic disaster preparedness and response, and natural resource management.

The United States Agency for International Development (USAID) is proud to continue our partnership with the National Aeronautics and Space Administration (NASA) and with the International Centre for Integrated Mountain Development (ICIMOD) in support of the SERVIR Hindu Kush Himalaya hub. While NASA and USAID have different mandates, our complementary partnership layers NASA's investments in technology and science with USAID's investments in promoting resilience in partner countries. It is through our partnerships with strong institutions such as ICIMOD that we are able to strengthen national and local capacity to access, process, and use remote Earth observation data and information, tailoring it to the needs of users so that they can better understand and manage risk. When applied to development challenges, technology has the power to spur inclusive economic growth, build resilience to climate change, and support pathways out of poverty.

In this book, SERVIR Hindu Kush Himalaya shares their experience in implementing a collaborative, user-centric approach to designing and delivering services that help government and civil society stakeholders identify and manage risk. SERVIR's consultative approach to assessing needs and building capacity to access and use timely, actionable information is an investment that empowers our partners to address and help solve the complex challenges of the twenty-first century.

We look forward to seeing SERVIR Hindu Kush Himalaya strengthen existing partnerships and forge new ones as they continue to improve the reach, impact, and sustainability of their services.

Greg Collins
Deputy Assistant Administrator,
USAID Resilience Coordinator,
Bureau for Resilience and Food
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Preface

The guiding principle of SERVIR, a joint initiative of NASA and USAID, has been "Connecting Space to Village"—a pretty ambitious statement that calls for Earth observation (EO) applications to be employed to address real problems on the ground. At the International Centre for Integrated Mountain Development (ICIMOD), SERVIR Hindu Kush Himalaya (SERVIR-HKH)—as the regional hub for the HKH region—has strived to achieve these objectives over the past decade by working on EO applications to deal with issues of regional priority. Over the years, technologies have advanced at a rapid pace, and the journey has been educative—especially in terms of understanding users' contexts and customizing solutions to their specific needs for greater meaning and effectiveness.

This book aims to capture our efforts in EO science and its applications to address environmental challenges in the HKH region, not only from a technological perspective, but also coming at it from the equally important cross-cutting aspects of user engagement, capacity building, communications, gender, and programme management. Our approaches, methodologies, technical details, and decade-long experience have been presented across the book's 19 chapters. These provide background and analysis of SERVIR-HKH's approaches to designing and delivering information services on agriculture and food security; water resources and hydro-climatic disasters; land cover and land use change, and ecosystems; and weather and climate services. Similarly, multidisciplinary topics including service planning; gender integration; user engagement; capacity building; communication; and monitoring, evaluation, and learning have been accommodated. We also document challenges and future perspectives for EO products and services in the HKH region through a unique focus on EO science and applications for improving environmental decision making in the complex landscape of the HKH.

Put together by 68 contributing authors and sharpened further by 44 reviewers, the book presents a complete package of knowledge on service life cycles with a collection of multi-disciplinary topics and practically tested applications for the HKH region. We expect that the EO and geospatial communities in the region and beyond will gain useful insights and benefit from our experience with focused and targeted interventions and user-centred approaches to develop impactful solutions.

We hope that this book will be a good reference document for professionals and practitioners working in remote sensing, geographic information systems (GIS), regional and spatial sciences, climate change, ecosystems, and environmental analysis. Furthermore, we are hopeful that policymakers, academics, and other informed audiences working in sustainable development and evaluation—both within the SERVIR network and beyond—will greatly benefit from what we have shared here on our applications, case studies, and documentation across cross-cutting topics.

Kathmandu, Nepal

Birendra Bajracharya
Rajesh Bahadur Thapa
Mir A. Matin
Editors

Acknowledgements

We acknowledge NASA's Daniel Irwin and USAID's Carrie Stokes, who conceived the idea of SERVIR—named so after the Spanish and French "to serve"—to complement the strengths of two United States agencies to utilize space technologies in development decision-making. Over the years, the programme—begun in 2005 in Mesoamerica—has grown into the global SERVIR network that works across five regions and over 50 countries to benefit communities around the world.

We are grateful to Basanta Shrestha, Director of Strategic Cooperation—and former Regional Programme Manager, MENRIS—at ICIMOD. His role in establishing the Hindu Kush Himalaya (HKH)-focused SERVIR-HKH hub in 2010 was pivotal. Since its establishment, SERVIR-HKH has demonstrated that the adoption of Earth observation information can support initiatives working to improve the lives and livelihoods of people in the HKH.

We also acknowledge the contributions of colleagues who have supported our work: Nancy Searby, Ashutosh Limaye, Gwen Artis, Lee Stewart, Eric Anderson, Walter Lee Ellenburg, Francisco Delgado, Tim Mayer, Helen Blue Baldwin, and others from the NASA SERVIR Science Coordination Office in Huntsville, Alabama; Jenny Franklin Reed, Albert Anoubon Momo, Pete Epanchin, Tom Zearly, and Karl Wurster from USAID; the NASA Applied Sciences Team (AST) Principal Investigators—Benjamin Zaitchik, Jim Nelson, Patrick Gatlin, Cedric David; and Carlos Quintela, Anthony Panella, and the entire SERVIR Support Team. Learning exchanges and collaborations with other regional SERVIR hubs also helped strengthen our services and applications.

We are grateful to ICIMOD's SERVIR-HKH team, which has contributed to its successful implementation. This book has been a joint effort at recording and explicating the various interventions made and lessons learnt by our team in the past decade. We hope these prove useful and interesting to those working on EO applications.

We would like to thank David Molden, former Director General, ICIMOD; Eklabya Sharma, former Deputy Director General, ICIMOD; and Ghulam Rasul, Regional Programme Manager, MENRIS, ICIMOD for their support and guidance in the preparation of this book as well as the implementation of SERVIR-HKH.

Thanks go to Laurie Vasily, Samuel Thomas, Utsav Maden, Rachana Chettri, Kundan Shrestha, Sudip K. Maharjan, and Jitendra Raj Bajracharya from the Knowledge Management and Communication Unit at ICIMOD and Shanuj VC, consulting editor, for their support in the preparation of the book.

Special thanks are due to Ganesh Bhattarai, Angeli Shrestha, and Rajesh Shrestha for their support to the smooth functioning of SERVIR-HKH. We would also like to thank colleagues from our partner institutions in Afghanistan, Bangladesh, Bhutan, Myanmar, Nepal, and Pakistan, who made significant contributions to the design, implementation, and use of the services critical to the success of SERVIR. We acknowledge all the authors for their contributions to this book, and all our reviewers for their thorough, constructive comments.

About SERVIR

SERVIR connects space to village by helping developing countries use satellite data to address challenges in food security, water resources, weather and climate, land use, and natural disasters. A partnership of the National Aeronautics and Space Administration (NASA), the United States Agency for International Development (USAID), and leading technical organizations, SERVIR develops innovative solutions to improve livelihoods and foster self-reliance in Asia, Africa, and the Americas.

SERVIR Hindu Kush Himalaya

The International Centre for Integrated Mountain Development (ICIMOD) implements SERVIR Hindu Kush Himalaya (SERVIR-HKH)—one of five regional hubs of the SERVIR network—in its regional member countries, prioritizing activities in Afghanistan, Bangladesh, Myanmar, Nepal and Pakistan. For more information, visit servir.icimod.org.

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Rajesh Bahadur Thapa is Remote Sensing and Geoinformation Specialist at ICIMOD. His work focuses on radar applications to monitor and assess terrestrial environments, and capacity building on Earth observation and geoinformation technologies in the region.

Mir A. Matin is Theme Leader for the Geospatial Solutions at ICIMOD. He provides scientific leadership in building and promoting innovative and user-oriented geospatial applications to support improved resilience and livelihoods in the region.

Acronyms

ACT	Australia Capital Territory
ADIM	Assessment, Design, Implementation, and Monitoring
ADPC	Asian Disaster Preparedness Center
AEZ	Agro-Ecological Zones
AFS	Agriculture and Food Security
AGU	Annual American Geophysical Union
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
AIMS	Afghanistan Information Management Services
ALOS	Advanced Land Observing Satellite
AMA	Afghan Meteorological Authority
AMD	Afghanistan Meteorological Department
ANDMA	Afghanistan National Disaster Management Authority
ANN	Artificial Neural Network
AOGEO	Asia-Oceania Group on Earth Observations
AOGEOSS	Asia Oceania Global Earth Observation System of Systems
APFM	Associated Programme on Flood Management
APHRODITE	Asian Precipitation—Highly-Resolved Observational Data Integration Towards Evaluation
API	Application Programming Interface
ARD	Application Ready Data
ARIES	Artificial Intelligence for Ecosystem Services
ARVI	Atmospherically Resistant Vegetation Index
ASHA	Adaptation for Smallholders in Hilly Areas
AST	Applied Sciences Team
AUROC	Area Under the Receiver Operating Characteristics
AVHRR	Advanced Very High Resolution Radiometer
AWiFS	Advanced Wide Field Sensor
AWS	Amazon Web Services
BARC	Bangladesh Agricultural Research Council

BARI	Bangladesh Agriculture Research Institute
BBC	British Broadcasting Corporation
BFD	Bangladesh Forest Department
BiDS	Big Data from Space
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
BSDMA	Bihar State Disaster Management Authority
BSI	Bare Soil Index
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
BYU	Brigham Young University
C3S	Copernicus Climate Change Service
CARE	Cooperative for Assistance and Relief Everywhere
CB	Capacity Building
CBD	Convention on Biological Diversity
CBS	Central Bureau of Statistics
CC	Cross Cutting
CC-BY	Creative Commons Attribution
CDF	Common Data Form
CEGIS	Centre for Environmental and Geographic Information Services
CEMS	Copernicus Emergency Management Service
CEO	Collect Earth Online
CEOS	Committee on Earth Observation Satellites
CF	Community Forestry
CFM	Community Forestry Management
CFUGs	Community Forest User Groups
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CHIRP	Climate Hazards Group InfraRed Precipitation
CHIRP/S	Climate Hazard Group InfraRed Precipitation Satellite
CI	Clean Ice
CIFOR	Center for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center
CIMR	Copernicus Imaging Microwave Radiometer
CNN	Cable News Network
CO2M	Carbon dioxide monitoring
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRED	Center for Research on the Epidemiology of Disasters
CRFMS	Climate Resilient Forest Management System
CRISTAL	Copernicus Polar Ice and Snow Topography Altimeter
DAE	Department of Agriculture Extension
DC	Debris-Covered
DDG	Deputy Director General
DDM	Department of Disaster Management

DEM	Digital Elevation Model
DEOC	District Emergency Operation Center
DFOMP	Divisional Forest Operation and Management Plan
DFOs	Divisional Forest Officers
DFRS	Department of Forest Research and Survey
DG	Director General
DHM	Department of Hydrology and Meteorology
DLRS	Department of Land Records and Survey
DMDD	Data Management Definition Document
DNPWC	Department of National Parks and Wildlife Conservation
DoA	Department of Agriculture
DoF	Department of Forests
DoFSC	Department of Forests and Soil Conversation
DOIs	Digital Object Identifiers
DORIS	Delft Institute of Earth Observation and Space Systems
DPHE	Department of Public Health and Engineering
DQA	Data Quality Assessment
DRAS	Drought Assessment Model
DRR	Disaster Risk Reduction
ECMWF	European Center for Medium Range Weather Forecasts
ECs	Executive Committees
EFFIS	European Forest Fire Information System
EFWS	Enhancing Flood Forecasting and Warning System
EL	Exposure and Learning
EMC	Environmental Modeling Center
EM-DAT	Emergency Events Database
EML	Ecological Metadata Language
ENSO	El Nino–Southern Oscillation
ENVISAT	Environmental Satellite
EO	Earth Observation
EO4SDG	EO for Sustainable Development Goals
ER	Elevation Rating
ERDAS	Earth Resources Data Analysis System
ESRI	Environment Systems Research Institute
ET	Evapotranspiration
ETDI	Evapotranspiration Deficit Index
ETM	Enhanced Thematic Mapper
EVI	Enhanced Vegetation Index
EWS	Early Warning Systems
FAO	Food and Agriculture Organization
FD	Forest Department
FECOFUN	Federation of Community Forestry Users Nepal
FEWS NET	Famine Early Warning Systems Network
FEWS	Flood Early Warning System

FF	Forest Fire
FFR	Forest Fire Risk
FFWC	Flood Forecasting and Warning Center
FOSS	Free and Open Source Software
FR	Frequency Ratio
FRA	Forest Resource Assessment
FRTC	Forest Research and Training Center
GARD	Generalized Analog and Regression Downscaling
GBIF	Global Biodiversity Information Facility
GCI	Green Chlorophyll Index
GDACS	Global Disaster Alert and Coordination System
GDAS	Global Data Assimilation System
GDEST	Global Dialogue on Emerging Science and Technology
GDP	Gross Domestic Product
GDWR	General Directorate of Water Resources
GEE	Google Earth Engine
GEF	Global Environment Facility
GEFS	Global Ensemble Forecast System
GEO	Group on Earth Observations
GEOBON	Group on Earth Observations Biodiversity Observation Network
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring Initiative
GeoGLOWS	GEO Global Water Sustainability
GEOS	Global Earth Observation System
GEOSS	Global Earth Observation System of Systems
GESI	Gender and Social Inclusion
GFMC	Global Fire Monitoring Center
GFOI	Global Forest Observations Initiative
GFS	Global Forecast System
GIAnt	Generic InSAR Analysis Toolbox
GIS	Geographic Information Systems
GIT	Geospatial Information Technologies
GLAD	Global Land Analysis and Discovery
GLDAS	Global Land Data Assimilation System
GLIMS	Global Land Ice Measurements from Space
GLOF	Glacial Lake Outburst Flood
GLoFAS	Global Flood Awareness System
GLOVIS	Global Visualization Viewer
GMI	GPM Microwave Imager
GMTSAR	Generic Mapping Tools Synthetic Aperture Radar
GNOME	Global Network for Observations and Information on Mountain Environments
GoN	Government of Nepal

GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRAIN	Grain Research and Innovation
GRD	Ground Range Detected
GWP	Global Water Partnership
HIWAT	High Impact Weather Assessment Toolkit
HKH	Hindu Kush Himalaya
HPC	High Performance Computing
HTESSEL	Hydrology Tiled ECMWF Scheme for Surface Exchange over Land
HTTP	Hypertext Transfer Protocol
ICIMOD	International Centre for Integrated Mountain Development
ICST	International Conference on Sensing Technology
IDMP	Integrated Drought Management Programme
IFAD	International Fund for Agricultural Development
IFS	Integrated Forecast System
IGES	Institute for Global Environmental Strategies
IGIF	Integrated Geospatial Information Framework
INGO	International Non-Governmental Organization
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IRS	Institute of Remote Sensing
ISCE	InSAR Scientific Computing Environment
ISO	International Organization for Standardization
ISODATA	Iterative Self-Organizing Data Analysis Technique
ISPAN	Irrigation Support Project for Asia and the Near East
IT	Information Technology
IUCN	International Union for Conservation of Nature
IUFRO	International Union of Forest Research Organizations
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modelling
JAWRA	Journal of the American Water Resources Association
JICA	Japan International Cooperation Agency
JPEG	Joint Photographic Experts Group
JPL	Jet Propulsion Laboratory
JRC	Joint River Commissions
JU	Jahangirnagar University
KFS	Korean Forestry Services
KFZ	Kandahar Food Zone
KGE	Kling-Gupta Efficiency
KMC	Knowledge Management and Communication
KU	Kabul University
LAI	Leaf Area Index
LAPA	Local Adaptation Plan of Action
LCCS	Land Cover Classification System

LCR	Land Cover Rating
LDAS	Land Data Assimilation System
LEOCs	Local Emergency Operation Centers
LFA	Lightning Forecast Algorithm
LGED	Local Government Engineering Department
LIDAR	Light Detection and Ranging
LIS	Land Information System
LISS	Linear Imaging Self Scanning Sensor
LoA	Letter of Agreement
LoI	Letter of Intent
LPG	Liquified Petroleum Gas
LRMP	Land Resource Mapping Project
LSM	Land Surface Model
LSTM	Land Surface Temperature Monitoring
LULC	Land Use and Land Cover
LULC&E	Land Use, Land Cover and Ecosystems
LWM	Land and Water Mask
M&E	Monitoring and Evaluation
MAE	Mean Absoulte Error
MAIL	Ministry of Agriculture, Irrigation and Livestock
MC	Mercy Corps
MCDA	Multi-Criteria Decision Analyses
ME	Mean Error
MEA	Millennium Ecosystem Assessment
MEL	Monitoring, Evaluation and Learning
MENRIS	Mountain Environment Regional Information System
MEW	Ministry of Energy and Water
MIID	Myanmar Institute for Integrated Development
ML	Machine Learning
MoALD	Ministry of Agriculture and Livestock Development
MODIS	Moderate Resolution Imaging Spectroradiometer
MoFE	Ministry of Forests and Environment
MoFSC	Ministry of Forests and Soil Conservation
MoHA	Ministry of Home Affairs
MoNREC	Ministry of Natural Resources and Environmental Conservation
MoPE	Ministry of Population and Environment
MoU	Memorandum of Understanding
MoWR	Ministry of Water Resources
MRV	Measurement, Reporting and Verification
MSFC	Marshall Space Flight Center
MSS	Multispectral Scanner System
MTAP	Medium Term Action Plan
MTR	Melghat Tiger Reserve
MyCOE	My Community Our Earth

NAMIS	National Agriculture Management Information System
NAP	National Adaptation Plan
NAPA	National Adaptation Plan of Action
NARC	Nepal Agricultural Research Council
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCHM	National Center for Hydrology and Meteorology
NDDBI	Normalized Difference and Distance Built-up Index
NDFI	Normalized Difference Fraction Index
NDMC	National Drought Monitoring Center
NDMI	Normalized Difference Moisture Index
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEPA	National Environmental Protection Agency
NFFMC	Nepal Forest Fire Management Chapter
NFI	National Forest Inventory
NGIC	National Geoinformation Center
NGO	Non-Governmental Organization
NHMS	National Hydrological and Meteorological Services
NIRAPAD	Network for Information, Response And Preparedness Activities on Disaster
NISAR	NASA-ISRO Synthetic Aperture Radar
NLCMS	National Land Cover Monitoring Systems
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
NRT	Near Real-Time
NSDI	National Spatial Data Infrastructure
NSE	Nash-Sutcliffe Efficiency
NSIA	National Statistic and Information Authority
NTFP	Non-Timber Forest Product
NTNC	National Trust for Nature Conservation
NU	Nangarhar University
NWARA	National Water Affairs Regulation Authority
NWP	Numerical weather prediction
OBIC	Object-Based Image Classification
ODC	Open Data Cube
ODK	Open Data Kit
OFDA	Office of Foreign Disaster Assistance
OGC	Open Geospatial Consortium
OJT	On the Job Training
OLI	Operational Land Imager

OPeNDAP	Open-source Project for a Network Data Access Protocol
OSM	Open Street Map
PA	Practical Action
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PARC	Pakistan Agricultural Research Council
PAs	Protected Areas
PBA	Partnership Brokers Association
PBIAS	Percent bias
PBL	Planetary Boundary Layer
PCRWR	Pakistan Council of Research in Water Resources
PDD	Definition Document
PIPA	Participatory Impact Pathway Analysis
PM&E	Planning, Monitoring and Evaluation
PMD	Pakistan Meteorological Department
PMEL	Planning, Monitoring, Evaluation and Learning
PMM	Probability Matched Mean
PNG	Portable Network Graphics
POD	Probability of Detection
PPCR	Pilot Program for Climate Resilience
PPGIS	Public Participation Geographic Information System
QGIS	Quantum Geographic Information System
RADAR	Radio Detection and Ranging
RAM	Random Access Memory
RAN	Robotics Association of Nepal
RAPID	Routing Application for Parallel Computation of Discharge
RBM	Result Based Management
RCP	Representative Concentration Pathway
RDAFRI	Relative Differenced Aerosol-Free Vegetation Index
RDMOS	Regional Drought Monitoring and Outlook System
RDR	Road Distance Rating
RDS	Regional Database System
RECOFTC	Regional Community Forestry Training Center for Asia and the Pacific
REDD	Reducing Emissions from Deforestation and Forest Degradation
REST API	Representational State Transfer-Application Program Interface
RF	Random Forest
RLCMS	Regional Land Cover Monitoring System
RMSE	Root Mean Square Error
ROI_PAC	Repeat Orbit Interferometry Package
ROSE-L	Radar Observing System for Europe—L-band
RS	Remote Sensing
RSR	RMSE-observations standard deviation ratio
S2S	Season to Sub-season
S2S-LDAS	Sub-Seasonal to Seasonal Land Data Assimilation System

SA	Spectral Angle
SAARC	South Asian Association for Regional Cooperation
SAC	SAARC Agriculture Centre
SAGE	Scientific Advisory Group for Emergencies
SALDAS	South Asia Land Data Assimilation System
SAR	Synthetic Aperture Radar
SASCOF	South Asian Climate Outlook Forum
SAVI	Soil Adjusted Vegetation Index
SCO-SOCRATES	SERVIR Coordination Office-SERVIR Operational Cluster Resource for Applications—Terabytes for Earth Science
SDG	Sustainable Development Goal
SDK	Software Development Kit
SDR	Settlement Distance Rating
SEPAL	System for Earth observations, data access, processing and analysis for land monitoring
SFD	State Forest Department
SFDRR	Sendai Framework for Disaster Risk Reduction
SFTP	Streamflow Prediction Tool
SIG	Spatial Informatics Group
SLR	Slope Rating
SMA	Soil Moisture Anomaly
SMEs	Subject Matter Experts
SMRC	SAARC Meteorological Research Centre
SMS	Short Message Service
SNAP	Sentinel Application Platform
SoB	Survey of Bangladesh
SOCRATES	SERVIR Operational Cluster Resource for Applications—Terabytes for Earth Science
SOP	Standard Operating Procedures
SoP	Survey of Pakistan
SPA	Service Planning Approach
SPARRSO	Bangladesh Space Research and Remote Sensing Organization
SPI	Standardized Precipitation Index
SPME	Strategic Planning, Monitoring and Evaluation
SPoRT	Short-term Prediction Research and Transition Center
SPOT	Satellite Pour l'Observation de la Terre
SPT	Streamflow Prediction
SQL	Structured Query Language
SRDI	Soil Resources Development Institute
SRTM	Shuttle Radar Topography Mission
SST	Sea Surface Temperature
ST	Standard Training
STEM	Science, Technology, Engineering, and Mathematics
SUPARCO	Pakistan Space and Upper Atmosphere Research Commission

SVM	Support Vector Machine
SWOT	Strengths, Weaknesses, Opportunities and Threats
TDD	Training Definition Document
TDOM	Temporal Dark Outlier Mask
THREDDS	Thematic Realtime Environmental Distributed Data Services
TM	Thematic Mapper
TOA	Top of Atmosphere
ToC	Theory of Change
ToT	Training of Trainers
TR	Temperature Rating
TRU	Thompson Rivers University
UAV	Unmanned Aerial Vehicle
UEMS	Unified Environmental Modeling System
UMD	University of Maryland
UN	United Nations
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNGGIM	United Nations International Group on Geospatial Information Management
UNISDR	United Nations International Strategy for Disaster Reduction
UNOOSA	United Nations Office for Outer Space Affairs
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
URL	Uniform Resource Locator
USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USF	University of San Francisco
USFS	United States Forest Service
USGS	United States Geological Survey
UTC	Universal Time Coordinated
VCI	Vegetation Condition Index
VDC	Village Development Committee
VGI	Volunteered Geographical Information
VH	Vertical transmissions and the horizontals received
VIC	Variable Infiltration Capacity
VIIRS	Visible Infrared Imaging Radiometer Suite
VRA	Vulnerability Reduction Assessment
VV	Vertical transmissions and the verticals received

WAPRO	Water Resources Planning Organization
WCS	Web Coverage Service
WFP	World Food Programme
WFS	Web Feature Service
WMO	World Meteorological Organization
WMS	Web Map Service
WRD	Water Resource Department
WRF	Weather Research and Forecasting
WRHD	Water Resources and Hydro-Climatic Disasters
WRI	World Resources Institute
WWF	World Wide Fund for Nature

Chapter 1
Earth Observation Applications in the Hindu Kush Himalaya Region—Evolution and Adoptions

Birendra Bajracharya, Daniel E. Irwin, Rajesh Bahadur Thapa, and Mir A. Matin

1.1 Introduction and Rationale

The year 1957 marked the start of a new era in human history with the launch of Sputnik, thus began the journey of Earth observation (EO). Then, in the early 1960s, with rapid developments in space technology and the race to reach the moon, scientific discussions veered toward the potential applications of EO in the fields of geography, agriculture, water resources, geology, and oceanography (NASA 2017; Haklay et al. 2018). The famous photograph of the rising Earth (Earthrise) taken from the lunar orbit in December 1968 by astronaut William Anders is considered the most influential environmental picture ever (Moran 2018). Astronauts have often expressed their experiences on looking at the Earth from space—a planet full of water and without borders—and how the sight made them feel small and vulnerable (Shrestha and Bajracharya 2011). Earth's images from space have urged us to think of and understand our planet as a system. The launch of Landsat 1 in 1972 symbolized the beginning of the modern EO era and provided a consistent set of synoptic, high-resolution images (80 m) to the scientific community (Zhou and Kafatos 2002). Since then, EO has proven to be a powerful tool to generate information across the globe—information that is consistent, transparent, reliable, verifiable, and not restricted by national borders.

Our daily lifestyles have dramatically changed in today's increasingly global, connected, and digital world, dictating how we spend our work and social life (O'Sullivan et al. 2018). EO data and services have become an integral part of modern society, ranging from monitoring global climate to navigating cars or exploring online detailed images of our neighborhood with our mobile phones. The

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_1

evolution of citizen science and volunteered geographic information (VGI) has resulted in concrete projects like OpenStreetMap (Brovelli et al. 2020). We are now accustomed to accurate hourly weather forecasts and to following satellite images of swirling storms hitting coasts and cities. A combination of satellite data and weather models has made it possible to forecast discharge in each stream segment and also the extent of flood two weeks ahead, thereby helping in better preparedness to tackle any potential disaster (Souffront et al. 2019; Nelson et al. 2019).

The wide range of information collected by EO directly or indirectly supports all functions of government, economic sectors and in tracking biodiversity and wildlife trends; it also helps in measuring land-use change and deforestation; monitoring natural disasters such as fires, floods, and earthquakes; managing natural resources, such as energy, freshwater, and agriculture; addressing emerging diseases and health risks; and predicting and mitigating climate change (Anderson et al. 2017; Petiteville et al. 2015; Paganini et al. 2018).

Today, all countries are facing complex challenges of climate and environmental, sociocultural, and economic changes which are having an impact on natural environments and livelihoods. This calls for immediate actions, both globally and locally. So, realizing the need for unified interventions, all member states of the United Nations have adopted the 2030 Agenda for Sustainable Development, which provides a shared blueprint for peace and prosperity for the people and the planet (UN 2015). The agenda includes 17 Sustainable Development Goals (SDGs), which the countries need to address in a global partnership. These goals, targets, and indicators have been designed to measure, manage, and monitor progress in a uniform and systematic manner across the globe. EO has a significant role to play in this regard by bringing in spatial dimension to natural resources and socioeconomic statistics, while also allowing for disaggregation and granularity of the indicators (Paganini et al. 2018). EO data can support in analysis, modeling, and mapping SDGs which can then provide the integrative and quantitative framework necessary for global collaboration, consensus, and evidence-based decision-making (Liu et al. 2020). The global interest in EO is also demonstrated by the membership of more than 100 national governments and over 130 participating organizations in the Group on Earth Observations (GEO) which envisions "a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive, and sustained Earth observations" (http://earthobservations.org). Moreover, initiatives such as the United Nations Office for Outer Space Affairs (UNOOSA) for promoting international cooperation in the peaceful uses of outer space, and its United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) are examples of international efforts in the use of EO for societal benefits (http://unoosa.org). UN-SPIDER supports the developing countries to have access to specialized EO technologies which are essential in the management of disasters and reducing disaster risks. EO-based applications and services are increasingly being used for emergency response (Petiteville et al. 2015) and environmental monitoring, which are mainly seen as humanitarian needs. EO is also contributing to the emerging markets and providing opportunities for small and medium enterprises, thereby being of value for citizens, government agencies, and the commercial industry (O'Sullivan et al. 2018).

It was the opening of the United States Geological Survey's Landsat archive in 2008 that greatly encouraged the development of applications using EO data. For the first time, a systematic, decades-long archive of our planet became freely available. The benefits to the US and international users from the Landsat imagery were estimated at $3.4 billion in 2017 (Straub et al. 2019). This open-data policy resulted in a 60-fold increase in daily data downloads and crossed 100 million downloads as of March 2020 (Zhu et al. 2019; Straub et al. 2019; USGS 2020). Meanwhile, the Copernicus Program of the European Union implemented similar policies by providing free and open access to the vast majority of data and information delivered by the Copernicus Space infrastructure and the Copernicus Services (Zhu et al. 2019; Reillon 2017; Filchev et al. 2018). In the case of Asia, China, India, Japan, and South Korea are the major contributors in this area with their large suite of satellites; they have also initiated open-access policies on some selected data sets. Another development in the field of EO is the considerable increase in CubeSats which have changed the way satellites are built, launched, and used to address different needs (Thyrso et al. 2019). Besides, the adoption of these disruptive satellite technologies by private players like Planet has made any part of Earth accessible on a daily basis (http://planet.com).

The large volumes of free Landsat, Sentinel, and many other resources in the application ready data (ARD) format provided through cloud computing services with programming interfaces and powerful processing capabilities is seen as the democratization of satellite mapping (Dwyer et al. 2018). Efforts are also being made by space agencies on joint development and continuous innovation in the space sector; these are driven by national security and science objectives, user needs, and the pursuit of human space exploration (Zhu et al. 2019; ESRE Whitepaper 2017). Today, we observe a rapid transformation in the international space sector alongside the emergence of Space 4.0, which has been characterized by increased interaction among governments, the private sector, society, and the political community (Mazzucato and Robinson 2017). This is often seen in conjunction with the Fourth Industrial Revolution that has transformed the production cycle which is now being driven by digital technologies such as artificial intelligence (AI), machine learning (ML), cloud computing, Internet of things (IoT), and big data analytics (Filchev et al. 2018; Vaidya et al. 2018). Meanwhile, many developments from other areas, such as data cube technologies and block chain, are being adopted or explored for implementation in EO applications (ESA 2019; Sudmanns et al.2019; O'Sullivan et al. 2018; Baumann et al. 2018). Then there is the factor of next-generation EO satellites which are expected to be highly intelligent and possessing the capability to integrate sensors, data-processing devices, and communication systems, thereby making it possible to carry out global surveys and real-time environmental analysis (Liu et al. 2020). With the maturity and convergence of these evolving technologies, we can expect unprecedented opportunities from EO to serve the needs of our communities, nations, and the world as a whole.

That said, despite these technological advances, there are many parts of the world where the communities and countries face enormous challenges driven by local and regional drivers of global climate change. The Hindu Kush Himalaya (HKH) in South Asia is one such region coping with immediate threats to its livelihoods, biodiversity, and ultimately, sustainability, due to human- and climate-induced changes. The HKH region covers parts or whole of Afghanistan, Pakistan, north-eastern and western Himalayas of India, the Tibetan plateau of China, Nepal, Bhutan, Bangladesh, and Myanmar. Also known as the third pole of the world and the "water towers" of Asia due to the vast reserves of freshwater on its mountains, it is the source of major Asian rivers and provides essential resources to around 1.9 billion people within and downstream of the region. Therefore, the environments and the natural resources of the HKH have both regional and global significance (Wester et al. 2019). Since 1983, the International Center for Integrated Mountain Development (ICIMOD), an intergovernmental organization based in Kathmandu, has been working in the areas of environmental conservation and protection of livelihoods in the HKH region (www.icimod.org).

As a knowledge and learning center, ICIMOD develops and shares research, information, and innovations in order to empower the people of the HKH region (ICIMOD 2018). Some of its priorities have been to bridge data gaps and avail of information technologies so as to promote evidence-based decisions at both local and national levels. In the case of applying and demonstrating EO and geospatial technologies in the region, ICIMOD has been working since the early 1990s by strengthening the capacity of national institutions to adapt to these new developments. Toward this end, specifically in 2010, ICIMOD became the host of the regional hub of a program called SERVIR. SERVIR is a partnership among the United States Agency for International Development (USAID), the National Aeronautics and Space Administration (NASA), and leading regional organizations. It develops innovative solutions to improve livelihoods and foster self-reliance in Asia, Africa, and the Americas. As a global program, SERVIR brings together a network of partners from NASA centers, research agencies, and other SERVIR regional hubs worldwide in order to work on the common problems that the countries are facing; it helps these countries adopt the latest methods and technologies, and designs appropriate services to address the problems. Empowering local institutions to use and adopt advanced technologies provides immense opportunities to tackle the complex socioecological problems in the challenging environment of the world's highest mountain region.

We, as part of SERVIR, have developed this book in order to share our approaches and methods developed over time, which we believe will be useful to the broader community that focuses on user-centered EO and geospatial applications and services. In this book, we have documented our experiences of a decade of implementing the SERVIR-HKH program that promotes EO applications to address the development challenges faced by the communities of the HKH region.

1.2 The Geographic Context

The mountains of the HKH region have attracted humans since ancient times as a sacred place to fulfill their spiritual quest. Besides, the challenges posed by the remoteness and tough terrain of the HKH mountains have drawn the attention of explorers and adventurers from all over the world. The HKH is characterized by mountain ranges that include all the highest peaks above 8000 meters from sea level; they separate the Tibetan plateau from the southern plains of the Indian subcontinent. The region extends over 3500 km, encompassing Afghanistan in the west to Myanmar in the east (Fig. 1.1). Ten large Asian river systems originate from the region, which include the Amu Darya, Indus, Ganges, Brahmaputra, Irrawady, Salween, Mekong, Yangtse, Yellow River, and Tarim (www.icimod.org).

The high variability in its topography makes the HKH region highly heterogeneous with unique microclimates and ecological conditions. This has spawned rich cultures and high biodiversity—the region accounts for all or part of four global biodiversity hotspots. But the region, home to the youngest mountains in the world, is rather fragile; this fragility stems from weak geological conditions, steep topography, strong hydrodynamics with short and intense monsoonal rainfall, and excessive human intervention. The communities who have lived with and adapted to the tough mountain environments for centuries are now facing frequent and unpredictable calamities in the form of floods, landslides, wildfires, and extreme weather (ICIMOD 2018).

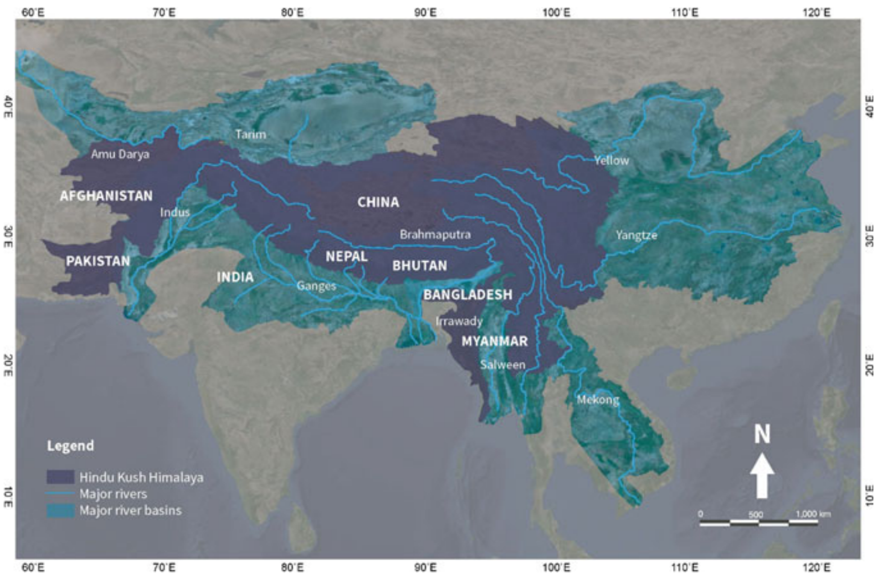

Fig. 1.1 Hindu Kush Himalaya region

Fig. 1.2 Farmlands in the high mountain district of Mustang, Nepal. Photo by Birendra Bajracharya

More recently, the HKH region has received growing attention as one of the most vulnerable ecosystems in the world; concerns have risen about rapid glacier melt and the consequent threats to water resources for both upstream and downstream communities (Wester et al. 2019). The visible impact of climate change on snow and glaciers, the water cycle, and biodiversity, as well as the increasing frequency and magnitude of climate-induced disasters is threatening the dynamics of life-support systems and the traditional adaptation and coping mechanisms of the local people (Bajracharya et al. 2007; Wester et al. 2019). The mountain communities still make their living from limited farmlands and natural resources (Fig. 1.2). However, recurring droughts are affecting agricultural production where access to water for farming was already under strain. The region is also facing multiple pressures from globalization by way of migration, unsustainable tourism, overexploitation of natural resources, and changes in land-cover and land-use practices (Wester et al. 2019).

1.3 Earth Observation Applications in the HKH

Understanding the complex natural and socioecological processes in the HKH has been challenging due to limited scientific data and information. Highly inaccessible terrains, harsh climatic conditions, and lack of investment in long-term scientific research are major constraints for routine data collection, both in terms of spatial and temporal dimensions. In this context, to overcome the inherent complexities of such a mountainous region, satellite remote sensing offers the only means for consistent and synoptic observations of the HKH. EO, in combination with geospatial tools and models, paves way for better scientific understanding of the regional scenarios on climatic and environmental changes in these previously inaccessible areas (Thapa and Murayama 2012; Nelson et al. 2019; Sikder et al. 2019).

It is in this sphere of science and technology that ICIMOD has been playing a pivotal role. As an organization working on bridging the gaps between science, policies, and practices, ICIMOD understands the importance of knowledge generation and sharing so as to achieve sustainable and resilient mountain development. As an early adopter of scientific systems and technologies, ICIMOD established the Mountain Environment Regional Information System (MENRIS) division in 1990 to promote the use of geographic information systems (GIS) and remote sensing (RS) applications focusing on mountain environments. More recently, we have seen the synergistic convergence of geospatial technologies with mainstream information technology; there has been widespread penetration of smart applications into everyday lives—even in the HKH region. The evolution of EO applications in the HKH can be clearly understood through the journey of MENRIS over the past three decades, which is briefly illustrated below.

1.3.1 First Decade (1990–2000): Introduction of Geospatial Technology in the HKH

In the first decade, MENRIS activities could be broadly outlined in terms of capacity building and preparation of baseline geospatial data. In its early days, generating awareness about the technology among professionals, scientists, and decision makers was itself a major task. Realizing that qualified and capable human resources is fundamental to the meaningful utilization of GIS and EO, MENRIS started a series of comprehensive training programs. Key nodal agencies were identified in each HKH member country and they were assisted with hardware and software to establish GIS facilities; this was done under special arrangements with the United Nations Environment Program (UNEP) and the Environment Systems Research Institute (ESRI). The trainings were based on the PC ArcInfo software running in a desktop environment, which made it affordable to the national agencies. This model of combining training programs with the provision of software allowed the trainees to continue working with the system after completing the training. Setting up GIS labs and organizing regular trainings with universities and other key institutions helped in preparing the much-needed foundation for such a venture in the HKH region.

A major challenge was that base maps in the digital form were nonexistent for any work to begin on any real application. So, efforts were made on developing databases using the available paper maps. Digitizing all the 1 inch: 1 mile scale topographic maps of Nepal and making them freely available to the users was a massive undertaking. Also, a number of demonstration projects were implemented with partners. Some of the early examples of application of GIS and EO in the region are: MENRIS case study series on Dhading (ICIMOD 1992), Gorkha (Trapp 1995), and Lamjung (Trapp and Mool 1996); Kathmandu Valley GIS database (Shrestha and Pradhan 2000); GIS for municipal planning in Kirtipur (Shrestha et al. 2003); and land-cover mapping of Nepal and Pakistan using the National Oceanic and Atmospheric Administration's (NOAA's) Advanced Very High-Resolution Radiometer (AVHRR) data (UNEP 1998).

In 1996, the project "Strengthening of Training Capabilities for GIS Applications in Integrated Development in the Hindu Kush Himalayan Region," funded by the Netherlands government, provided a further boost to develop structured capacity building activities with new courses on Infrastructure and Facility Planning; Mountain Agriculture and Land-use Planning; Monitoring, Assessment and Planning of Mountain Natural Resources; and Slope Stability Analysis and Hazard Mapping (Shrestha and Bajracharya 2002). These month-long trainings were organized in all member countries of ICIMOD. The technical trainings and policy workshops helped to generate the required skill sets among professionals from governments and relevant agencies, thereby raising awareness among the decision makers. During this time, the development of more user-friendly software interfaces on Windows, such as Esri's ArcView and Erdas Imagine, helped to improve the learning curve of the beginners and made it possible to include more advanced analytical tools in the trainings.

1.3.2 The Second Decade (2000–2010): Transition to Internet-Based Applications and Decision-Support Systems

MENRIS started its second decade by focusing on the emerging approaches in capacity building. A computer-based CD-ROM on "Applications of GIS and Remote Sensing to Sustainable Mountain Development" was developed—with concepts of geospatial technology, interactive and hands-on exercises, and supplementary materials—for the trainers to serve as a self-learning kit and as an aid in professional-level training programs. Internet map services were also introduced through ICIMOD's Mountain GeoPortal with interactive online training materials.

And from the years 2006–2009, advanced applications of EO on socioecosystem modeling were initiated through a Hindu Kush–Karakoram–Himalaya (HKKH) partnership project supported by the Italian Development Cooperation of the Ministry of Foreign Affairs. This partnership initiative took place under the umbrella of the global mountain partnership with the purpose of consolidating institutional capacity for systemic planning and management of mountain resources at regional, national, and local levels. It focused on developing decision-support tools for conservation management in the three of the most elevated protected areas of the world: Everest National Park in Nepal; Chomolungma Nature Preserve in China; and Karakoram National Park in Pakistan (Bajracharya et al. 2010a). During this time, MENRIS adopted emerging and innovative approaches such as object-based classification for studying land-cover dynamics using high-resolution IKONOS imagery (Bajracharya et al. 2010b); integration of GIS visualization with system dynamics models on various socioeconomic drivers of change; and the implementation of web-based platforms for sharing data and applications. The second decade of MENRIS enabled the transition from desktop-based systems to server technologies on GIS/RS applications. In addition, MENRIS was also engaged in habitat suitability analyses in the eastern Himalayas, above-ground biomass estimation in the community forests of Nepal for Reducing Emissions from Deforestation and Forest Degradation (REDD), and in the preparation of glacier and glacial lake inventory of the entire HKH region (Chettri et al. 2010; Bajracharya and Shrestha 2011; Bajracharya et al. 2007). Over these two decades (1990–2010), ICIMOD, through MENRIS, had established itself as a regional resource center for providing innovative solutions which integrated GIS and remote sensing. ICIMOD also became a participating member of the GEO and worked with regional and international partners on fostering regional cooperation for improved access to and use of geo-based knowledge for the benefit and development of the mountain communities. Currently, ICIMOD is leading the Himalayan GEO, one of the task groups of the Asia Oceania GEO (AOGEO), with objectives to foster regional collaboration on EO applications and to link the priorities of the HKH region with global initiatives.

1.3.3 The Third Decade (2010–2020): Transformation from Applications to Services with SERVIR-HKH

While developing decision-support tools and researching similar work in other parts of the world, the MENRIS team came across the SERVIR-Mesoamerica website and noted that it had objectives which were very similar to MENRIS's. Subsequently, SERVIR and ICIMOD officials met at a GEO meeting in Athens in 2009 where the initial concept of SERVIR-Himalaya was discussed. (By this time, SERVIR had already established a new hub in East Africa in addition to its first hub —SERVIR-Mesoamerica, which was established in 2005.) Thus, by working on common objectives, ICIMOD became a SERVIR hub for the HKH region. The implementation of SERVIR in the HKH can be split into two phases.

SERVIR Phase 1 (2010–2015)

SERVIR-Himalaya formally started operations in July 2010 and was officially launched during the international symposium on "Benefiting from Earth Observation: Bridging the Data Gap for Adaptation to Climate Change in the Hindu

Kush Himalayan Region," which was organized from October 4–6, 2010 in Kathmandu. Among those who attended the launch event were NASA Administrator Charlie Bolden, USAID Senior Deputy Assistant Administrator Michael Yates, GEO Secretariat Director Jose Achache, as well as senior government officials from the HKH countries and scientists from the region and beyond. The international symposium and the regional inception workshop set up a sound stage for SERVIR-Himalaya among the regional partners in ICIMOD member countries and clearly demonstrated SERVIR's relevance in the region (Shrestha and Bajracharya 2011).

The scope of SERVIR-Himalaya was defined within four major areas of its results framework: capacity building of ICIMOD as the regional center for EO applications; building the capacities of national institutions in the region; promoting platforms for data sharing; and developing customized tools and products to support decision-making. While SERVIR-Himalaya was the third hub to join the SERVIR network, the ground realities differed greatly from those prevailing in the other two hubs in Mesoamerica and Africa. The countries of the HKH region had their own individual institutional setups, and the national capacities of these countries varied largely in terms of EO technologies. It was then realized that the essence of developing successful EO applications lay in focusing on the needs of the national institutions and the end users of the system.

A preliminary needs assessment was carried out to identify the key regional issues and the national priorities and capacities of the institutions of the HKH countries before initiating the design and development of information products and services (ICIMOD 2010). The assessment focused on a wide range of issues which were often interrelated, involving a large cross-section of institutions and people from different countries with different levels of capacity. Therefore, a qualitative approach was adopted with standard tools for the needs assessment—these are more intuitive than quantitative methods. As part of this effort, in order to analyze relevant recent and ongoing initiatives and to identify potential users and partners, several activities were carried out: literature reviews; consultation workshops; focus group meetings with the management and professionals; and questionnaire surveys in Bangladesh, Bhutan, China, India, Nepal, and Pakistan. The user landscape included government ministries and departments which were the mandated institutions and primary stakeholders, UN organizations and donors, universities, local governments, and non-governmental organizations. The needs assessment reinforced the fact that the information system and the databases in the region were weak and needed to be developed; and that remote sensing and modeling technologies were at a very early stage of development or even nonexistent. So, there was a need for the professionals to have hands-on experience in climate models with the capacity to capture complex terrain features and also a need to improve understanding about the regional and local dimensions of vulnerability.

A demand–supply model (Fig. 1.3) was then framed, looking into the demand for better information and supplying high-quality, user-tailored tools, and information services. A number of science applications were designed, using satellite data and predictive models, to develop the visualization tools that had been

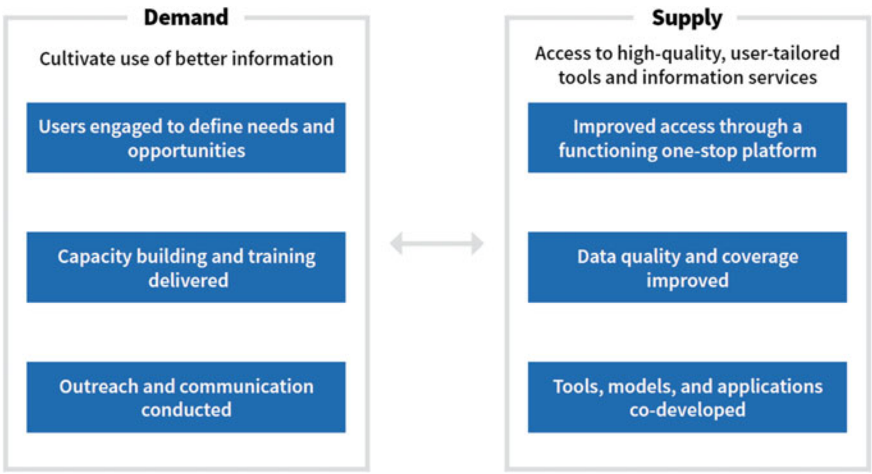

Fig. 1.3 Demand and supply model

prioritized based on the needs assessment; another aspect that was considered was the feasibility of availing data and technologies. The assessment had focused on the themes of cryosphere, ecosystems and biodiversity, disaster risk reduction, and transboundary air pollution (Table 1.1). Detailed assessments and implementation plans for each science application were then prepared by identifying user requirements, products, and methodologies. Each application was planned to be made accessible through web-enabled systems and also included user-friendly tools and functionalities.

In addition to the science applications being developed by the hub, there were three applied sciences projects which were implemented through NASA grants by a SERVIR applied sciences team; these projects also enabled US-based research organizations to complement the hub's activities. The projects were: a study led by Arizona State University on glacier and alpine hazards in relation to development and habitation; a study led by the University of Washington on early warning, mapping, and post-disaster visualization of the water resources of low-lying deltas; and a study led by the R&D organization Battelle on the use of satellite products for air quality monitoring, analysis, and visualization.

In order to promote the involvement of national/local-level organizations in the applications of EO and geospatial technologies, two streams of a small grant program were also implemented. One set of eight grants was provided through an open call, while another six grants were provided through a selective call for proposals. These included applications that varied from flood forecasting, hazard mapping, and UAV for REDD, to the assessment of grazing intensity for rangeland management, engaging local citizens in agricultural mapping, and the dissemination of community-based forest-fire information. These applications were carried out by agencies in Bangladesh, Nepal, Pakistan, and India. All the small grant programs

Table 1.1 List of science applications in SERVIR-Himalaya (Phase 1)

Theme	Science application	Geographic coverage
Cryosphere and water	MODIS-based regional snow-cover area mapping and monitoring system	HKH region
	Run-off modeling using the CREST model in Bhutan under different climate change scenario	Bhutan
Ecosystem and biodiversity	Multiscale biomass assessment models and the REDD+ MRV process	Nepal
	Land-cover change and GHG inventories	Bhutan, Nepal
	Phobjika wetland habitat conservation studies	Bhutan
	Development of rangeland decision-support system in the HKH region of Pakistan	Pakistan
	Forest-change proneness modeling	Bhutan, Nepal, Bangladesh
Disaster management	Forest-fire detection and reporting system	Bhutan, Nepal
	Wireless sensor network for community-based flood early warning system	Bangladesh
Agriculture food security	Satellite-based crop monitoring and production assessment	Nepal
Air quality monitoring	Regional aerosol mapping using MODIS and AERONET station data	HKH region

had components of fieldwork and engagement with communities, which was enormously useful in catalyzing innovative ideas and bringing them to the local level.

Since the beginning of SERVIR-Himalaya, there has been a building up on past efforts and approaches of MENRIS in designing and organizing training programs. For example, the aspect of focusing on youth was strengthened through youth forums and through programs like NASA DEVELOP and My Community, Our Earth (MyCOE). All of these added new dimensions to the capacity building efforts.

SERVIR Phase 2 (2015–2020)

The start of the second phase of SERVIR in 2015 saw new arrangements in the hub's operations. First and foremost, at the beginning of the new phase, the hub was officially renamed as SERVIR-Hindu Kush Himalaya (SERVIR-HKH) and expanded to include a specific component on Afghanistan. In the first phase, the contract management of the USAID development funds for SERVIR at ICIMOD was conducted through an agreement with NASA; in the second phase, it was through USAID. In this new configuration, NASA optimized its role to focus on: science coordination and technical backstopping; connecting the hub in a better way with the scientific communities; facilitating connection with subject-matter experts; providing access to EO data and methods; and giving support on Geospatial Information Technology (GIT). In this phase, NASA continued to support and expand its use of competitive grants through the SERVIR applied sciences team and worked toward better alignment of the selected projects to the needs of the hub. NASA grants are awarded to US-based organizations (academic, non-governmental, the private sector, and the government, besides NASA centers) through a competitive open call. In the second phase of SERVIR, USAID assumed the responsibilities of funding and procurement through its global development mandate and coordination with its regional and bilateral missions. Also, a global SERVIR support team (SST), managed by USAID, was formed to support the hub in functions such as communications, monitoring, evaluation, and learning (MEL), and to facilitate exchanges outside and across the network of SERVIR hubs (Fig. 1.4).

The experiences of the first phase showed that a supply-driven approach tended to limit its focus to the available technologies and data resources while designing applications. Although these applications are somewhat simpler to develop, their use was often short lived due to the limited consideration of the problems they were designed to address as well as by not giving enough attention to the people who were supposed to use them. In the second phase of SERVIR, a services approach was implemented and adopted as a holistic framework—it began with the “problem” for which a solution is needed and kept the user at the center of design, delivery, and implementation. This approach not only resulted in a better

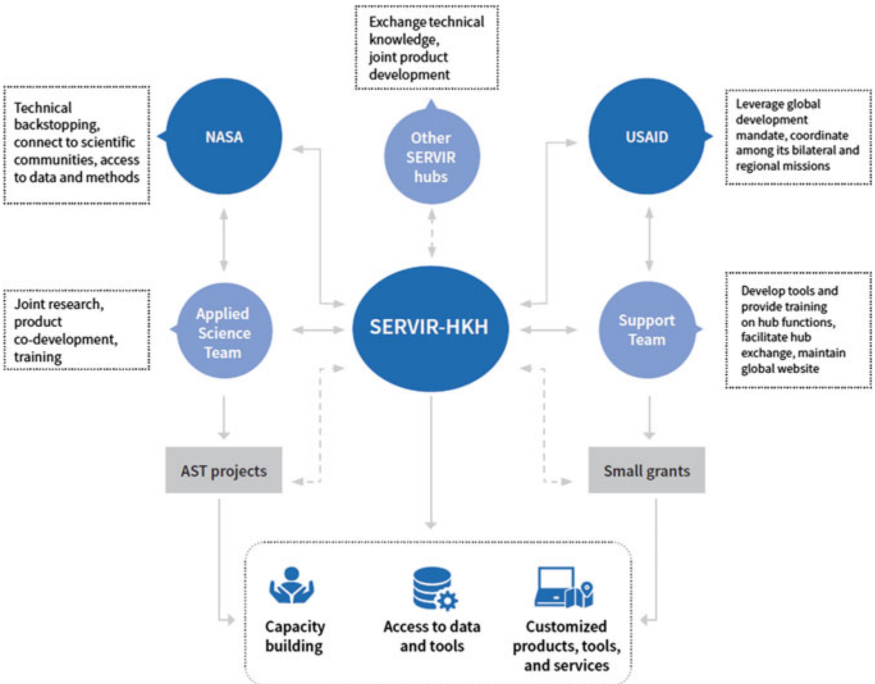

Fig. 1.4 SERVIR network

understanding of user needs but also enabled true co-development with the end users, ultimately leading toward long-term impact. As part of this effort, SERVIR-HKH contributed to the SERVIR Service Planning Toolkit which has become an invaluable resource to adopt the services approach in order to pave way for better design, delivery, and implementation of EO services for long-term impact.

To bring uniformity across the network of SERVIR hubs, four broad service areas were identified: agriculture and food security; land use, land cover, and ecosystems; water and hydro-climatic disasters; and weather and climate. With all the hubs adopting a common framework and working on the same priority service areas, the opportunities increased for cross-hub collaborations. The four SERVIR applied sciences team projects in the second phase also focused on: the implementation of a South Asia land data assimilation system; enhancement of stream-flow prediction; assessment of high-impact weather; and estimation of snow-water resources. The tools and methods provided by these projects were closely integrated with the development of services on agricultural drought, flood early warning systems, and extreme weather forecasts (Table 1.2).

Since the applications of EO are heavily dependent on technology, SERVIR-HKH recognized that ensuring adequate GIT infrastructure and human resources are equally important to create enabling environments at the hubs and with implementing partners. Dissemination platforms for delivering appropriate and timely information to the users are a critical component of SERVIR-HKH. Depending upon the nature of the service, SERVIR-HKH has developed information systems that vary from simple query and visualization applications to advanced, fully automated systems which allow users to visualize data and information in various formats such as dynamic maps, charts, tables, and infographics. In addition, a number of mobile-based field-data collection tools have been developed, taking advantage of the growing use of smartphones in the region. The

Table 1.2 List of SERVIR applied sciences team projects in Phase 2

S. No.	Project description	Area covered	Leading institution
1	Comprehensive stream-flow prediction and visualization to support integrated water management	HKH/ Bangladesh, Nepal	Brigham Young University
2	Monitoring intense thunderstorms in the HKH region	Bangladesh, Bhutan, Nepal	NASA-Marshall Space Flight Center
3	Seasonal prediction of HKH hydrological extremes with the help of the South Asia land data assimilation system	HKH	John Hopkins University
4	Managing the changing nature of water resources south of the Himalayas	HKH	NASA-Jet Propulsion Laboratory

core principle of free and open access to data is central to SERVIR's approach in generation of information and providing access to all of its information services.

Another major effort of SERVIR-HKH has been to fill the capacity gaps among individuals and institutions in the use of EO information products and systems for evidence-based decision-making. As part of this effort, SERVIR-HKH developed a capacity building strategy to address the needs at various levels and to ensure sustained institutional capacities at national and local levels. Trainings related to the science and technologies adopted in the different services developed by SERVIR-HKH are given priority while keeping abreast with emerging technologies such as cloud computing, Synthetic Aperture Radar (SAR), and machine learning. Special trainings are designed to target young women and high-schoolteachers in order to increase awareness and interest among women professional to adopt careers in GIT, as well as to reach out to the local communities through schoolchildren.

SERVIR's adoption of the service approach has also put extra emphasis on gender, user engagement, and communications. SERVIR-HKH recognizes the need to consider gender impacts beyond just the use of a wide range of technologies. Thus, efforts are made to explore connections between gender and GIT, by including gender-related information to improve decisions involving the issues of the most vulnerable and marginalized groups in society. SERVIR-HKH has also developed a gender strategy and action plan to improve upon the methods of collecting gender-disaggregated data; the plan also seeks to customize information services to address gender needs; besides, it aims to promote GIT careers and women's participation in capacity building. The area of service planning also entails a knowledge management and communication strategy for targeted communication, sharing, and dissemination of the knowledge generated by SERVIR-HKH; this is to foster use by the target audiences and ultimately trigger behavioral change. Such knowledge shared and delivered to the users in appropriate formats, through relevant channels at appropriate timings, is central toward enabling any stakeholder to take informed decisions.

User engagement in the context of SERVIR-HKH is a multifaceted, multi-stakeholder, and multi-country complex phenomenon with both challenges and opportunities. SERVIR-HKH's user-engagement strategy ensures the systematic involvement of users at different stages either as co-creators, co-designers, co-implementers or as potential beneficiaries. Starting with the assessment of the user landscape and stakeholder mapping, the users are then engaged in various consultations and training events. Formal mechanisms such as a memorandum of understanding (MOU), a letter of agreement (LOA), and a letter of intent (LOI) are brought to bear for long-term collaborations with key institutions. These instruments are enormously valuable for institutional continuity should key personnel leave, be transferred, or if there is a change in government in the countries where SERVIR-HKH works.

Ultimately, all the efforts being made by SERVIR at the global level and in the regions are driven by the goal to create lasting impacts on the lives and livelihoods of the communities through the best use of the available EO and GIT resources. We strive to achieve our goals by defining theories of change and by identifying impact pathways. We believe that an MEL framework will guide us through the pathway and expedite learning and the adoption of new knowledge as we move along in our journey to connect "Space to Village"—the mantra of SERVIR.

The diversity of socioeconomic and political contexts, the complex user landscape, and the various types of services that have been developed have provided enormous learning opportunities to us during the design and implementation of the services. This book is an outcome of our learnings during the evolution of approaches and processes from phase one to phase two where we managed the priorities of users and professionals and aligned with the technological advances in the global market.

1.4 Overview of the Book

This book consists of nineteen chapters including this chapter. In this book, we refer to the HKH hub at ICIMOD as SERVIR-HKH, while SERVIR represents the global network including all the hubs. Chapter 2 explains the services approach and the SERVIR Service Planning Toolkit. It describes the major components of the toolkit and provides an example of its implementation in one of our services. Chapter 3 explains our efforts in understanding the gaps, needs, and priorities of national agencies in using EO and GIT for decision-making. Here, we present a study and its findings to understand the mandates of the key agencies and the status of their capacity and resources to develop and use geospatial tools. The study methodology includes literature review, institutional surveys, and key informant interviews, which resulted in findings related to different aspects of EO applications, ranging from current research and knowledge generation to human resources and the IT environment, as well as data-sharing policies at national and agency levels.

Adopting agriculture and food security as a priority service area is justified by the fact that the HKH region is predominantly an agrarian society with the majority of the population depending on agriculture for their livelihoods. The agricultural practices in the region largely depend on monsoonal rain which has been experiencing increased anomalies due to changes in climate. A wealth of climate and EO information is available from the past few decades which has been helpful in monitoring, modeling, and understanding the climatic variables—this can help in decision-making and agricultural planning. Chapter 4 presents our services on drought monitoring and in the establishment of an early warning system for the same that not only supports national- and local-level planning, but also provides agro-advisory services for preparedness to mitigate the impacts of drought on agriculture. In this regard, regional and national drought monitoring and outlook systems have been developed, which covers Afghanistan, Bangladesh, Nepal, and Pakistan. Chapter 5 focuses on another important area of EO applications in agriculture—the assessment of in-season crop area; this is critically important for national food security strategies. For example, SERVIR-HKH initiated a wheat-mapping activity in Afghanistan in response to a high-level request from its Ministry of Agriculture, Irrigation, and Livestock (MAIL). Then, an operational system for in-season monitoring of wheat crop was developed, utilizing optical (Sentinel-2) and Synthetic Aperture Radar (SAR, Sentinel-1) data, and by integrating decision trees and a machine learning algorithm in the Google Earth Engine cloud platform. In this chapter, we present the methodologies, the findings, and the institutional challenges that had to be tackled during the implementation of this system.

Chapter 6 presents the Regional Land-Cover Monitoring System (RLCMS) and the national systems which are implemented in Afghanistan, Bangladesh, Nepal, and Myanmar. The availability of free online satellite data and advances in cloud computing platforms such as Google Earth Engine made it possible to develop RLCMS and adopt it for generating more frequent land-cover maps at regional and national scales. The methodology was initially developed by SERVIR-Mekong and then was adopted for the HKH region through a multi-hub, co-development process. Chapter 7 presents another service that provides scientific data and information on the vulnerability of forest ecosystems to climate change and anthropogenic drivers; this service involves the use of ecological modeling techniques to support the identification and implementation of adaptation and forest-management strategies. One of the important drivers of forest degradation is forest fire, which has adverse ecological and economic effects. A reliable and timely fire detection and monitoring system is an important component of forest-fire management. Chapter 8 presents the forest-fire monitoring system developed by SERVIR-HKH. The innovative system identifies forest fires through the hotspot data generated by the Moderate Resolution Imaging Spectroradiometer (MODIS), and uses forest masks and overlays of administrative units. It sends SMS and email alerts to the corresponding authorities in the event of fire incidents in their area, as well as to the relevant national department. The forest-fire monitoring system has been useful in enhancing understanding about the spatial and temporal patterns of fire incidents and in identifying the vulnerable areas. The system also includes a function to report fire incidents from the field, thus making it a two-way process whereby data can be captured from both space and at the community level.

The HKH region is a hotspot of predominantly natural hazards, with frequent floods and extreme weather events playing havoc with people's lives and livelihoods. The services on water and hydro-climatic disasters include enhancing the flood early warning system, rapid flood mapping using multi-temporal SAR images, and mapping and change assessment of glaciers and glacial lakes. Chapter 9 presents our work on enhanced flood early warning, which is based on the novel stream-flow prediction tool that increases flood-forecast lead times in Bangladesh, Bhutan, and Nepal. This includes an operational 15-day flood forecast that integrates local data into a global model using methods co-developed by applied science team and local experts. Longer lead times and access to accurate and appropriate information ensure better preparedness for disaster responders, who can then help save lives and property. While early warnings can reduce the impacts of flood on lives and properties, timely and rapid flood inundation mapping plays an important role in rescue and relief operations, as well as in post-flood damage assessment. Chapter 10 presents our work on an operational methodology for rapid flood inundation mapping which helps in assessing flood situations. Since the monsoon period is always cloudy, we use Sentinel-1 SAR images during this period to prepare maps of the inundated areas. These areas are overlaid with pre-flood land-cover maps in order to identify settlements and agricultural areas, and the maps are distributed to the different agencies working on flood response and relief. In Chap. 11, we present our work on mapping glaciers and glacial lakes in Afghanistan. In response to a request from the Ministry of Energy and Water in Afghanistan, SERVIR-HKH carried out a study of glacier and glacial lake dynamics from 1990–2015 for the entire country. Glaciers are key freshwater resources and play a significant role in local and regional hydrology; they also carry with them the threat of glacial hazard. The glacier and glacial lake database were prepared by applying the semiautomatic object-based image classification method using Landsat imagery from the years 1990, 2000, 2010, and 2015; in this exercise, each glacier was mapped. In the 25-year period, the study not only showed a significant decrease in the number of glaciers but also recorded how the formation and expansion of glacial lakes have been adversely affected. Under the service area of weather and climate, a High-Impact Weather Assessment Toolkit (HIWAT) was developed to facilitate probabilistic forecasting and to assess the hazards associated with high-impact weather. Presented in Chap. 12, HIWAT consists of a real-time, convection-permitting ensemble numerical weather prediction system based on the Weather Research and Forecasting (WRF) model and a situational awareness tool that gauges thunderstorm intensity through satellite measurements. The forecast is disseminated to the stakeholders via an innovative data visualization platform. The precipitation registered in the forecast is also used in a routing model to predict flash floods in smaller watersheds.

Enabling environments that support the various services are very important where these enablers ensure that the services are efficiently deployed and also used by the target audience in an effective manner. Chapter 13 introduces the various information systems and mobile data collection tools developed by SERVIR-HKH. It provides details on the overall application development process and on the various types of technologies that are in use. Chapter 14 presents the capacity building strategy adopted by SERVIR-HKH and its implementation for strengthening the capacities of government organizations, development stakeholders, and individuals on the use of EO and GIT applications. Overall, it covers capacity gaps and identifies needs; it also dwells on facets such as structured planning, implementation, monitoring, evaluation, and successive learnings. It illustrates the four categories of training processes —standard training, training of trainers, on-the-job training, and exposure learning— that were strategically carried out by SERVIR-HKH with a focus on priority service areas. Chapter 15 describes our efforts in integrating the aspect of gender into service planning and design, and how the participation of women was promoted through various initiatives. As the prevalent inequality between women and men is bound to influence the development of technologies, this chapter tracks the connection between gender and technology over the decades and discusses how SERVIR-HKH integrates gender concerns into its program and activities.

Next, in Chap. 16, we deliberate over the importance of communications in providing the right type of data at the right time and in translating data visualizations into decisions. As we all know, communication plays a crucial role in making science available and accessible to the people. Since its inception, SERVIR-HKH has adopted an integrated approach toward communication processes; it has facilitated internal knowledge sharing and network-wide communications, as well as fostered brand recognition and trust among partners; dissemination and outreach too have played key roles. In place was also a communication strategy that guided the knowledge management and knowledge-sharing processes; various online and offline tools too were in use to help SERVIR-HKH achieve its strategic goals. Chapter 17 presents the key learnings while strengthening engagement with the users. This chapter highlights the impact of embedding the user-engagement approach, more particularly emphasizing that if the users are given ownership, there is a greater chance that products and services will be used effectively. In Chap. 18, we share our experiences on how the MEL practice enhanced result orientation, adaptive management, mutual understanding, and ownership by the stakeholders. This ultimately leads to better user-tailored EO products and services, and ensures the adoption and use of EO and GIT in evidence-based decision-making for the benefit of the vulnerable communities. We explain our learnings systematically with evidences and examples from the region.

Finally, the Chap. 19 has its spotlight on the lessons, challenges, and opportunities in the use of EO and GIT applications and services via SERVIR-HKH. Over the years, there have been significant developments in the field of EO and GIT while the capacity of the key agencies to leverage these advancements to produce, disseminate, and use the information has been rather limited. However, there are many opportunities in the region to fill the existing gaps in data, capacity, and services while simultaneously there is an increasing acceptability of EO and GIT as a means to improve the decision-making process in national institutions. It is observed that the partners' confidence has been growing on the use of SERVIR-HKH applications and services, and that enormous progress has been made on all fronts. The SERVIR network and its partnership with many institutions throughout the world provide excellent opportunities to usher in the latest advancements in science and technology and create broader perspectives in addressing the problems plaguing the HKH region.

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Chapter 2
Service Planning Approach and Its Application

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2.1 Introduction

In the first phase, SERVIR-HKH placed high importance on developing application products and tools to demonstrate the usefulness of Earth observation (EO) and geospatial information in supporting decision-making on various thematic areas including land cover mapping, forest fire monitoring, agriculture and food security, disasters, and air quality monitoring (Chap. 1). Although the application products and tools were prioritized based on the country needs assessments, they were largely driven by the available data, technology, and research interest of scientists (Bajracharya 2015). The products and tools were often developed with limited user interactions. The products were delivered to the users mostly in the form of online applications with interactive map visualization and often with data download capabilities. This method of product development assumed a full understanding of user needs, and that the developed products would be used by the targeted users. In reality, many of the application products ended up unused or less used by the targeted users. In some cases, there was a lack of clarity on the integration of the products and tools for decision-making within and beyond the user's organizations. Although the development of applications and tools addressed the perceived issues in the region, the limited engagement of partners in the development and validation process failed to produce user-friendly information per user expectations. Consequently, this limited the use of the applications and tools.

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https://doi.org/10.1007/978-3-030-73569-2_2

The institutional and operational aspects beyond science and technology were not sufficiently considered for the long-term sustainability of the application products. For products and tools to be used and operationalized, user engagement efforts need to be increased such that partner organizations, including government agencies, co-develop these products and tools, and have increased ownership of them (Bajracharya 2015, Chap. 17). Based on these lessons through the years, we realized that the mere connection between user consultations and the application products that have been developed are not adequate for achieving the intended sustainable impacts. Co-development among a SERVIR hub and stakeholder organizations requires a clear understanding of the information-driven decision-making challenges, the usefulness of the products, and formal partnerships. Therefore, there is a need for a pathway to encourage stakeholder communities and potential users to be active collaborators during the iterative stages of problem definition, product development, and delivery stages.

In this context, SERVIR developed a service planning approach in 2017 as a structured pathway to deal with these challenges and to shift the focus from developing application products to building services in collaboration with its partners to support their mandated responsibilities. SERVIR defines a "service" holistically as either data, information, tools, products, platforms, and training, or a suite of all these items offered to a stakeholder. Service planning, therefore, is a systematic process of designing and integrating user needs and preferences into the service delivery approach, to ensure that the process is responsive and effective. The service planning approach integrates stakeholders, partners, and the broader user communities into service planning discussions, starting with the identification of local challenges, then going through the design, tailoring, and delivery of services that use EO and geospatial information to address these challenges. In addition, identifying existing mechanisms where services can be integrated for sustainability is another important aspect of service planning. The service planning approach was adopted by all SERVIR hubs which continue to learn from practical applications. In this chapter, we highlight the modalities of the service planning approach and its implementation at SERVIR-HKH hub.

2.2 Service Planning Approach

The service planning approach provides a well-defined process for end-to-end implementation of service by actively engaging stakeholders, partners, and end users, starting from service conceptualization to adoption. The systematic engagement of users in service planning ensures the usability of the service, improves the service quality, and creates a pathway to the sustainability of the service. It aims to articulate the intended impact upfront through the development of a theory of change (ToC). Great attention is paid to maximizing the impact of the service through effective co-development and sustained delivery with the partners. The approach aims to include diverse voices and perspectives and engages representatives across gender and geographic regions for developing and providing customizable solutions. Service planning starts with user consultations, and the user engagement should continue over time, incorporating user feedback and allowing for the adaptive management of the service design and development. In most cases, the impact of the service will relate to improved decision-making and policy action and response, in areas such as environmental and natural resource management, disaster preparedness, food security, sustainable livelihoods, and resilience to shocks and stresses. Monitoring, evaluation, and learning (MEL) throughout the service cycle allow for the assessment of the service's ToC (Chap. 18).

The service planning approach can be presented as a cycle that iteratively defines the problem and identifies solutions to address it for making a positive impact (Fig. 2.1). The cycle is envisioned in three stages: needs assessment, service design, and delivery. A robust, easy-to-use service planning toolkit (SPT 2017), was developed in 2017 as a resource to provide applied guidance on the implementation of the service planning approach. This toolkit is a resource for designing user-centric geospatial information services that achieve meaningful impacts. The cyclical approach of service planning allows for constant improvement, refinement, and adaptation to changing contexts and changing information. A number of steps and activities are suggested for each of the three stages of service planning.

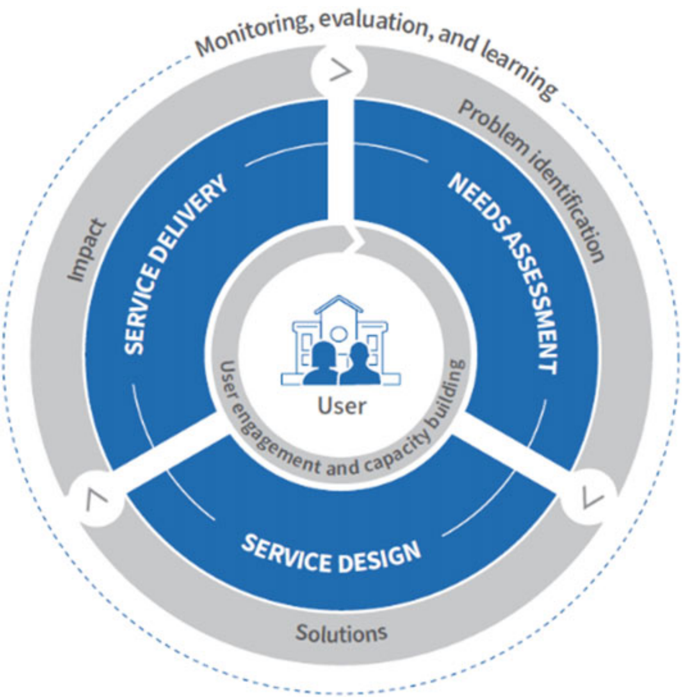

Fig. 2.1 Service planning lifecycle

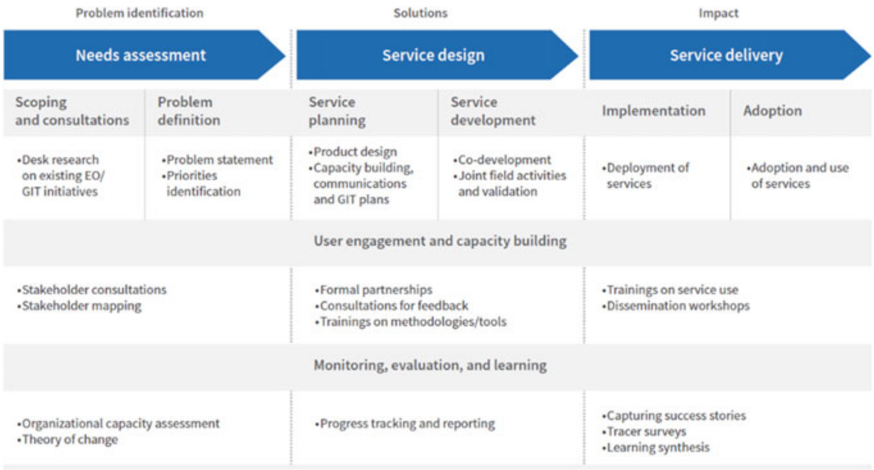

Fig. 2.2 Steps followed in service planning

The toolkit includes guidance for consultation and needs assessment for effective problem identification, with recommendations for workshop agendas and activities; stakeholder mapping; service design; and monitoring, evaluation, and learning, with templates for developing a ToC.

Here, we present the implementation of the service planning approach with examples from one of our services on the regional land cover monitoring system (RLCMS). The land cover monitoring system is being developed at the HKH regional and national levels (NLCMS) in Afghanistan, Bangladesh, Myanmar, and Nepal to address the need for consistent and efficient mapping which can be replicated on an annual basis. Details of the overall service on RLCMS are presented in Chap. 6.

2.3 Steps in Service Planning

Service planning is broadly designed in three stages (Fig. 2.2): problem identification which focuses on a clear understanding of needs; providing solutions through service design; and achieving impact through service delivery which is ensured by proper implementation and adoption by the intended users. User engagement and capacity building are considered as key activities throughout the service planning cycle. Moreover, the learnings from monitoring and evaluation are applied iteratively to improve service planning across all of its stages.

2.3.1 Stage 1: Needs Assessment

Scoping and Consultation

The needs assessment begins with a scoping and consultation process by engaging stakeholders to identify the user needs in a selected thematic area. Taking stock of related activities is important; the review of previous tools and applications of SERVIR as well as those being developed by other organizations in a given thematic area helps to understand the problems in broad terms. It is important to accurately capture the existing problems and challenges, to prioritize among multiple problems, and to understand the context of the problems and the underlying assumptions. An effective approach is to organize consultation workshops to bring people together to engage in dialog to identify the needs, priorities, and challenges. A structured format is followed for the workshops which is designed to be relevant for regional, national, and local consultations, even with a few stakeholders. Some context-specific customization is also done in the design of the workshop as needed.

The capacities among different organizations and users relevant to the service are also discussed during the workshop. This is followed by the organizational capacity assessments of selected organizations which would be partners in the co-development of the service. Capacity assessment includes meetings with key influencers, focus group discussions, semi-structured interviews, and technical assessment questionnaire surveys. The outputs from this step include a situational analysis of the problems in the particular thematic area and of the key priorities and capacities of the stakeholders. Consultation and needs assessment are perceived as continuous processes, required to be conducted or revised even during service design and delivery, in order to refine, adapt, and accommodate the findings during the implementation process.

During the implementation of RLCMS, a regional consultation workshop was organized in Bangkok where the national representatives from Afghanistan, Nepal, Bangladesh, and Myanmar participated, along with co-development partners from SERVIR-Mekong, FAO, SilvaCarbon, and the US Forest Service (USFS). The goal of the workshop was to learn from the national contexts as well as to understand common issues from the service development perspective. The deliberations on technical approaches and methodologies were useful in bringing all the participants to a common understanding of the needs and proposed solutions. Each country had different land cover mapping initiatives undertaken in the past with varying approaches and definitions of classes. Looking at the broader needs and country-specific priorities, it was evident that a common methodology would address the needs. However, specific considerations were required to define and derive certain land cover classes in each country. Similarly, national workshops were organized for each country, including for the wider user groups from these countries, so as to identify national needs and priorities, and the requirements for designing tailored solutions for countries within a regional system. An example of the different steps in the service planning of RLCMS is presented in Fig. 2.3.

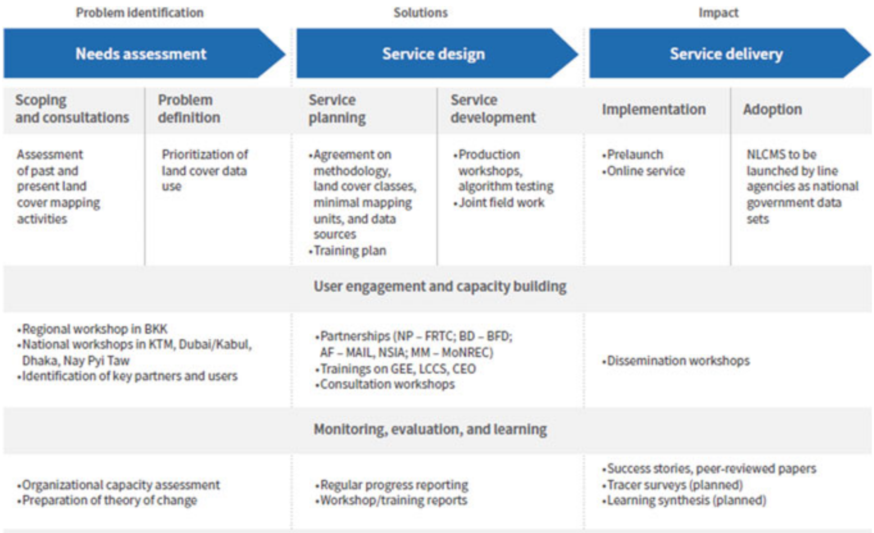

Fig. 2.3 Example of service planning implemented for a land cover monitoring system

Problem Definition

The next step in the needs assessment is to define the problem. Usually, many problems are brought up during the consultation workshops, which are discussed and then prioritized. Many of these problems are beyond the scope of SERVIR or the solutions are not feasible with the currently available EO information and geospatial technologies. Therefore, the problem is explicitly defined in the context of the solutions that will be provided by the service. At this stage, efforts are made to make it clear "why" the service will be developed and "what" problems will it address.

A stakeholder mapping exercise was carried out to identify the major stakeholders and users. It gives an understanding of institutional mandates and key players in the thematic area. The stakeholder mapping tool (SPT 2017) analyzes relationships and identifies gaps and opportunities related to the achievement of a particular goal by looking into the details of stakeholder practices or behaviors to desired outcomes. In addition, the tool helps to refine the understanding about stakeholders' ability to facilitate service design, implementation, and uptake; identify roles for services and opportunities to leverage other related activities; and to fathom the links between the services and the decision-making processes. In short, stakeholder mapping helps in identifying the targeted beneficiaries and in finding out potential partners who can play specific roles in co-development and delivery of the service.

While there are many approaches to stakeholder mapping, the service planning toolkit recommends information flow as a basis since SERVIR's work usually revolves around strengthening evidence-based decision-making. With this view, the main stakeholder types are considered as: (i) data collector—persons or institutions responsible for collecting primary or secondary data; (ii) data analyzers—entities involved in the analysis of data for the preparation of products and tools; (iii) intermediaries—responsible for the communication or dissemination of information between the data analyzers, decision makers, and beneficiaries; (iv) enablers—those not directly involved in the information system, but who influence the policy environment; (v) decision makers/end users—those with the authority to make decisions based on the data, products, and tools produced by the information system; and (vi), beneficiaries—those who benefit from the decisions informed by the system. A single stakeholder can fall into multiple categories. An example of a stakeholder map in the context of the National Land Cover Monitoring System for Nepal is illustrated in Fig. 2.4.

In this case, FRTC is the organization mandated to conduct land cover mapping in Nepal. It was the logical partner for SERVIR to engage to co-develop the service. Other sectoral departments or subnational offices such as the Department of Forests and Soil Conservation (DoFSC) were involved as data analyzer/producer since it is directly responsible for the forest sector data. Other agencies like the Department of National Parks and Wildlife Conservation (DNPWC), the Ministry of Agriculture and Livestock Development (MoALD), and the Central Bureau of Statistics (CBS) play the role of intermediaries which lend support in the communication, dissemination, and use of the information services. The end users include

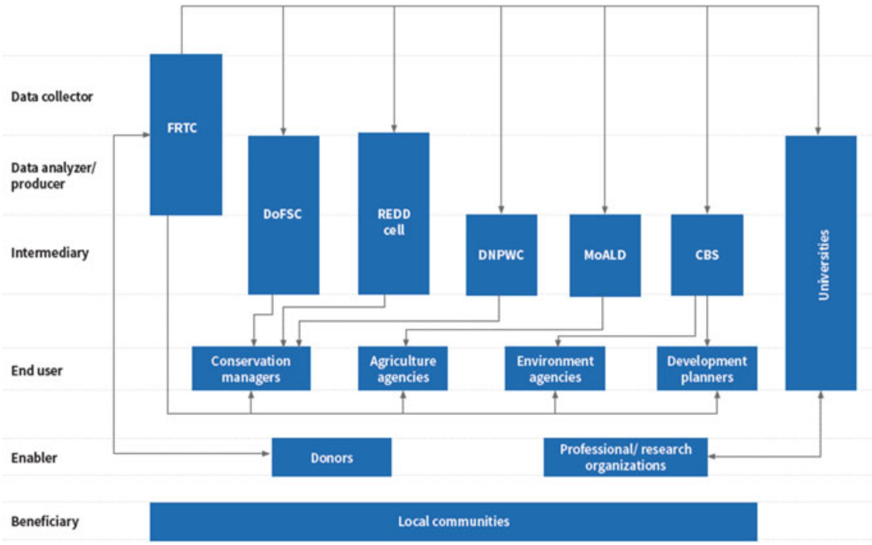

Fig. 2.4 Example of stakeholder map and information flow for the National Land Cover Monitoring, Nepal. Forest Research and Training Center (FRTC), Department of Forests and Soil Conservation (DoFSC), Department of National Parks and Wildlife Conservation (DNPWC), Ministry of Agriculture and Livestock Development (MoALD), and Central Bureau of Statistics (CBS)

conservation managers, development planners, and agricultural and environmental agencies which use the information in their decision-making process. Donor agencies and professional/research organizations are considered as enablers as they influence the policies for use or the reach of the service. The beneficiaries are those who benefit from the more accurate and timely information and management decisions made by the implementing partners, which include farmers, local communities, and the private sector.

Another component of problem identification is developing a ToC which defines the pathways to achieve the intended impacts from the service. The ToC is a comprehensive description and illustration of how and why the desired change is expected to happen in a particular context (https://www.theoryofchange.org/). It starts with the desired impacts and works backwards to identify the conditions or outcomes that must be in place to achieve those impacts. Clear outcome and impact statements are formulated to guide the planning, monitoring, and evaluation process, and to track the changes brought about by the use of the service to measure its impact. The ToC is considered as an ongoing process of reflection to explore change and how it happens while implementing the service (Vogel 2012). A brief template of ToC for RLCMS is provided in Table 2.1.

Table 2.1 Theory of change for the regional land cover monitoring system

Impacts	Sustainable land management, reduced loss of biodiversity, and enhancement of forest cover
Outcomes	Enhanced capacity of partners/stakeholders in monitoring changes in land cover for effective management
Outputs	• Annual land cover maps for the HKH region using a unified methodology, classification schema, and data sets • Annual national land cover maps based on nationally accepted classification schema • Web-based data visualization and analysis system for dissemination of land cover data and change information • Trained professionals in land cover mapping and monitoring
Inputs	• Consultations and stakeholder engagement for co-development of the classification schema and methodology • Land cover mapping and change analysis methodology (using Google Earth Engine and Landsat data) • Training of partners • Dissemination (workshops) on the complete system
Assumptions	• Stakeholders will use the annual land cover information in decision-making • The land cover classification system will overcome the technical challenges in mountainous and shadow-dominated areas • Sufficient cloud-free Landsat images will be available for the region • Google Earth Engine will be available as an open system for image analysis
Sustainability strategy	The capacity of the partner will be enhanced, and the whole methodology and system will be customized and automated for easy adoption by partners

At the end of the needs assessment stage, it is expected that we have a clear sense of the problems to address; an understanding of the information environment around the service and of the roles of the implementing partners, users, and beneficiaries; required inputs, including data and human resources; knowing about the capacity gaps of the different stakeholders; comprehending the relationships between the stakeholders and understanding their roles, and how they can contribute to the development and use of the service; and a well-defined ToC for the service.

2.3.2 Stage 2: Service Design

The design step sets up an environment of collaboration with the implementing partners on service design; development of data sets, products, and tools; on necessary capacity building activities; and on the dissemination strategy to support uptake.

Service design is the critical phase in which the hub and implementing partners come together to formulate a functional service. During this phase, they come to a consensus on the service requirements and the anticipated impact on a defined problem. The key driver of service design is a commitment by all parties to plan, implement, and sustain an effective response to the problem at hand. Partnerships are established with key organizations that have committed to the co-design and development of the service through formal instruments such as a memorandum of understanding (MoU) or a letter of intent (LoI), or via data-sharing agreements, depending upon the nature of the organizational setup. Sometimes, this process is lengthy due to the procedural requirements of government bureaucracies. However, work usually can advance under mutual, informal understandings between the agencies while formal relationships are being pursued. A partnership landscape in the context of RLCMS is given in Fig. 2.5.

Service Planning

Following the consultations and needs assessment and stakeholder mapping, service planning begins with consensus on a service concept and evolves into detailed planning to make the concept a reality. The service concept enhances concurrence in technical approaches and capacity building approaches; cultivates relationships, consolidating long-term user buy-in and ownership; and documents key aspects of developing and implementing the service. It helps to articulate the service vision, leading to impacts, and reflects an understanding of baseline technical capacity, data availability, gaps, and trainings and capacity needs. Besides, it is helpful to specify the technical details and other activities related to the various components of service design and delivery, including about products, data management, and capacity building. The service concept is supported by three additional documents: product definition document (PDD); data management definition document (DMDD); and training definition document (TDD). The PDD provides a

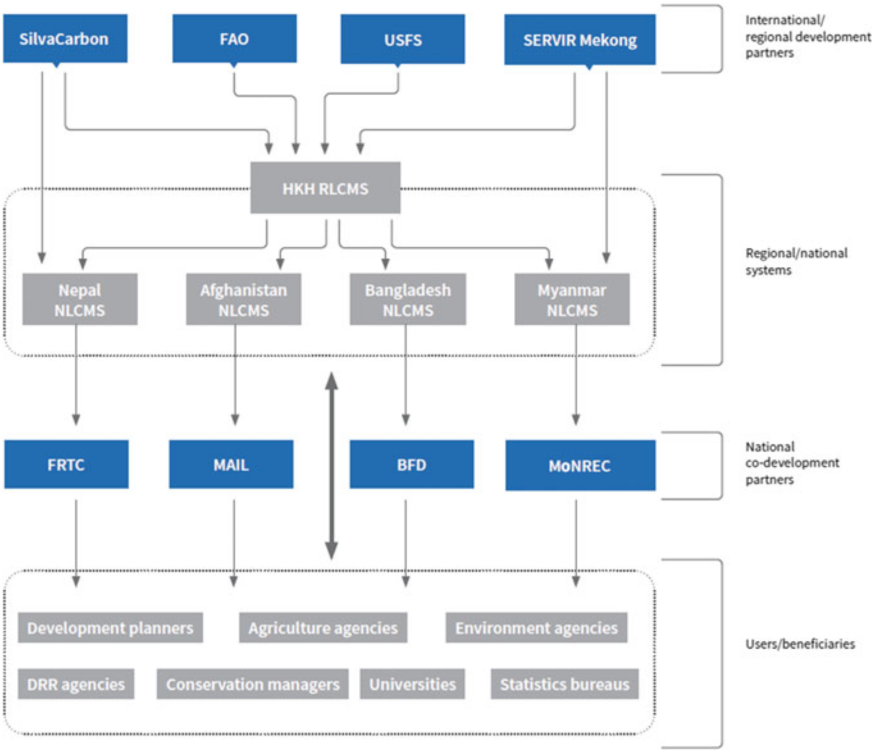

Fig. 2.5 Example of the partnership landscape for regional/national land cover monitoring systems. Forest Research and Training Center (FRTC), Ministry of Agriculture, Irrigation, and Livestock (MAIL), Bangladesh Forest Department (BFD), Ministry of Natural Resources and Environmental Conservation (MoNREC), Disaster Risk Reduction (DRR), United States Forest Service (USFS), Food and Agriculture Organization (FAO), Hindu Kush Himalaya Regional Land Cover Monitoring System (HKH RLCMS), and National Land Cover Monitoring System (NLCMS)

comprehensive technical approach to service development, including the roles of respective partners. In the case of RLCMS, the PDD includes details such as methodologies on using the Google Earth Engine (GEE), employing Landsat as the primary data source, and accessing Collect Earth Online for data collection through high-resolution satellite images, classification approaches, and minimum mapping units.

The DMDD describes the creation of platforms to support a service and also outlines a structured arrangement for data sharing. This document ensures sustainability, and data-sharing considerations for new data platforms are factored in at the start of the service design process. The TDD provides an overview of the anticipated capacity building and training activities. For RLCMS, a number of trainings on land cover classification and GEE were conducted for the selected staff from the partner organizations in each country. The training activities were designed as structured courses, production workshops, and on-the-job training. Collaboration with SilvaCarbon, USFS, FAO, and the SERVIR-Mekong hub were clearly defined for specific inputs during the training exercises.

Service Development

The next step after service design is the development of system components as defined in the PDD. Technical teams, consisting of relevant professionals from the hub, the NASA Science Coordination Office, the Applied Science Team and partner organizations, work together in the development of the different products contributing to the service.

User engagement during this phase includes regular meetings and consultation workshops organized jointly with the co-development partners. These consultations can be seen as follow-up activities to the needs assessment step; here, the primary focus is to provide updates on the development process and to receive feedback from the stakeholders. These consultations are useful in confirming the alignment of service development with the identified needs and priorities, which may have deviated to some extent from the previous findings. Any modifications that are required due to technical or institutional challenges are also identified through these user consultations. The frequent and regular engagement among service developers, users, and beneficiaries sets up the service implementers to achieve the intended outcomes.

Following the plans specified in the TDD, the major activity during this phase is organizing trainings to the targeted staff on the various software tools that are used in product development. Structured class room style training, on-the-job training, and production workshops are the modalities usually adopted for capacity building. During this phase, the RLCMS saw a series of trainings at the hub, and for co-development partners on GEE, there were also joint workshops for finalizing the land cover primitives and classes, as well as joint fieldwork. The strong sense of ownership demonstrated by the co-development partners, which are also nationally mandated organizations, ensured the utility and sustainability of the service in the long run.

2.3.3 Stage 3: Service Delivery

Service Implementation

At this stage, all the products planned under the service are finalized. The feedback and endorsement from the relevant line agencies are received through dissemination workshops. The accuracy of the data and information products are ensured using standard accuracy assessment methods. The online platform is developed to serve the data to the users with features for interactive visualization.

The beta version of land cover data for Nepal was released at a prelaunch workshop jointly organized by FRTC and SERVIR-HKH to which the relevant stakeholders were invited. An online application, as well as a mobile app, was developed to receive users' feedback on areas where the land cover was wrongly classified. After incorporating the users' feedback as well as after additional field verification from FRTC, the data were finalized. Further workshops are planned for endorsement from the sectorial agencies. The data will be finally released as the national land cover data set produced by the Government of Nepal.

Adoption

Dissemination workshops and orientation/training on the use of services are organized for broader awareness and adoption of the data and information generated through the service. With proper completion of all the stages of service development and implementation, it is expected that the data and information products will be used by the intended stakeholders and users in their decision-making process, thereby bringing positive impacts on policies and on communities. The evidence of the adoption and use will be captured through news articles, published papers, and the narration of success stories.

Performance Monitoring, Evaluation, and Learning

The MEL practice (Chap. 18) is considered as an essential component of the service planning approach, and it spans through the full cycle. MEL also evolves to expand the use of impact-driven planning and monitoring tools.

During the needs assessment of stage 1, MEL focuses on organizational capacity assessments and developing a ToC for the service. The ToC captures the "how" and "why" of the desired change in a particular context and brings clarity to the logic underpinning MEL. The MEL tools ensure the identification of changing perspectives, inputs, activities, outputs, outcomes, and impacts; promote effective implementation and sustainability of the services; identify measurements for progress; and highlight the logic of a service concept.

The MEL tools capture periodic progress through a number of predefined indicators. The metrics used for the indicators help in identifying whether the activities are going in the right direction in achieving the results as planned during the design and development of the service. During the service delivery stage, MEL helps in systematically capturing success stories. Capturing success stories are encouraged at this stage to demonstrate the utility of the services and attract more users who can benefit from them. MEL tools, like tracer survey and the repetition of organizational capacity assessment, help us in identifying the changes, and we have been able to bring as well as show us the areas of improvement for effective adoption of the service.

2.4 Experiences from Adopting the Service Planning Approach

As discussed in Chap. 1, the first phase of SERVIR-HKH started with the technological possibilities from EO applications and matching them with the users' demands in designing and developing products. The service approach has brought a paradigm shift in developing products or solutions by putting the "problems" first and working backwards from the desired impacts and outcomes toward the intermediate outputs and inputs that are required. SERVIR's capacity building goals are better achieved through a service approach that is composed of needs assessments, tools, products, and training; these are required to solve the identified problems. The service planning toolkit provides a guide to consider the full cycle of service planning. However, the tools need to be applied by taking into consideration the experience and context that are unique to each service. SERVIR works on the four service areas of agriculture and food security; land use, land cover, and ecosystems; water and hydro–climatic disasters; and weather and climate land cover and ecosystems, water and related disasters, and weather and climate (Chap. 1). The development outcomes, stakeholders, and challenges that span these four service areas are rather diverse, and therefore, the technical complexities also vary in the design of services. On the other hand, some problems in these service areas are interrelated. For example, an extreme weather event causes floods and landslides, which can destroy farms and bring changes in land cover types. Therefore, it becomes important to keep in mind the cross-connections among the services, products, and stakeholders. To address this, we came up with a matrix of products and services (Table 2.2) to identify the overlaps.

As with the services, the users also overlap and interact for different services. For example, the hydro-met agencies, with whom we co-develop services related to streamflow, weather, and climate, are often mandated to provide information to stakeholders in other service areas related to agriculture, water resources management, and disaster risk reduction. The capacities of the users and their access to the information systems also vary within a country and in the region. Therefore, user engagement and capacity building plans need customization according to the context. Another experience that we gathered from the service design and user engagement process is that there are substantial differences in the attitude of the institutions in the region. For instance, some are more open to experimenting with and adopting new technologies and information sharing, while others are very reticent to change (probably because they may face significant institutional risks in deviating from the current information and technology workflows; or the resources may be limited to participate in co-development). This demands a differentiated approach in engaging with partners and users.

From our experience, we have learnt that the service planning process usually takes more than three years, from the stage of needs assessment to the phase of service delivery. During this period, there are sometimes significant changes in the external landscapes, such as the start of larger projects at the national level dealing

Table 2.2 Products and services matrix

Products	Services								
	Regional drought monitoring and early warning	Agromet advisory service at national/ local levels planning	Food security vulnerability information system	In-season wheat crop area assessment	Enhancing flood early warning system (EWS)	River/ floodplain information management	Regional land cover monitoring	Forest vulnerability and management information	Monitoring extreme weather
South Asia land data assimilation system	X	X			X				
Regional drought indices analysis and visualization system	X								
Quantification of the total terrestrial water storage anomaly and groundwater anomaly	X	X			X				
Quantification of snow water equivalent	X	X			X				
Agromet advisory support portal		X							
Crop-type map for major crops (rice, wheat, maize)		X							

(continued)

Table 2.2 (continued)

Products	Services								
	Regional drought monitoring and early warning	Agromet advisory service at national/ local levels planning	Food security vulnerability information system	In-season wheat crop area assessment	Enhancing flood early warning system (EWS)	River/ floodplain information management	Regional land cover monitoring	Forest vulnerability and management information	Monitoring extreme weather
Food security information system			X						
Wheat area assessment and mapping system				X					
Mobile application for field data collection		X		X					
Regional hydrological model for discharge monitoring and forecast					X				
National/ regional-level viewer for visualization of ECMWF/GLOFAS					X				
Floodplain information portal						X			

(continued)

Table 2.2 (continued)

Products	Services								
	Regional drought monitoring and early warning	Agromet advisory service at national/ local levels planning	Food security vulnerability information system	In-season wheat crop area assessment	Enhancing flood early warning system (EWS)	River/ floodplain information management	Regional land cover monitoring	Forest vulnerability and management information	Monitoring extreme weather
Regional land cover monitoring system							X		
Forest vulnerability and degradation mapping								X	
Resilient forest management system								X	
Short-term weather forecasting					X				X
Extreme weather monitoring									X
Damage assessment due to extreme weather									X

with the same issues on which SERVIR has been working, or changes in the organizational structure of the government which directly affect the individuals and organizations partnering in co-development. The service design process must adapt to these external dynamics as we move into service delivery. Similarly, new technological platforms may emerge during the implementation phase, which can have a significant impact on product design. These changing landscapes, whether triggered by internal changes in government, by external influences from development and donor agencies, or by scientific and technological progress, further underscore the importance of iterating with users in reassessing and refining the needs, ToC, and intended outcomes of the services which are to be co-developed.

Although dissemination workshops were planned for RLCMS, it was not possible to organize the workshops physically during the final stages of service development due to safety issues and travel restrictions that were enacted to protect the citizenry from the COVID-19 pandemic. As an adaptation measure, SERVIR-HKH took to the virtual meeting platform to engage with the partners and stakeholders in order to disseminate the service; this has helped us achieve the expected outputs/outcomes as in the case of conventional meetings.

2.5 Conclusion

The keys to the service planning approach are to engage with the stakeholders in jointly focusing on problem identification, solutions, and impacts. While focusing on these keys, the approach encapsulates stakeholder consultation and needs assessment, stakeholder mapping, service design, monitoring and evaluation, and service delivery. User engagement, gender considerations, capacity building, and effective communication approaches are also fundamental aspects to improving service delivery and the sustainability of the services. To guide the successful implementation of the service planning approach, SERVIR was able to develop a service planning toolkit with four sets of tools. Each tool provides an opportunity to the hubs and the implementing partners to consider: (1) disproportionate effects of a development problem on audiences, (2) whether their needs are adequately addressed, and (3) whether the design and delivery of services can be strengthened to help reduce their vulnerability. The service concept and theory of change documents have advanced our ability to account for and integrate the needs of our stakeholders through the co-development of services. In this chapter, we have briefly described how implementing the service planning approach relies on the expertise and careful interpretation of the challenges faced by the implementing partners. Before the implementation of the service planning approach, the development of products lacked a shared vision to create sustainable information services in partnership with national or regional stakeholders. In addition to making the hub services more effective, the service planning approach adopted by the global network of SERVIR hubs, USAID, and NASA has enabled knowledge sharing among science and development practitioners in the Americas, Africa, and Asia. Enhanced by knowledge exchanges, the systematic documentation, consistency, and shared expectations of the service planning approach have enabled SERVIR hubs to find solutions in terms of data products, tools, platforms, methods, user engagement, capacity building, and outreach strategies from one region to another.

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Chapter 3
Geospatial Applications in the HKH Region: Country Needs and Priorities

Mir A. Matin and Sheikh Tawhidul Islam

3.1 Introduction

Geospatial information, defined as information that refers to a location on Earth, is becoming a critical tool in governance (Chantillon et al. 2017). Over the last decade, such information has become part of mainstream information management, thereby creating a massive demand for geospatial content and solutions among individuals, private companies, and government agencies. The industry has been growing at an annual rate of 14% and impacting the global economy at a rate of 18% (GEOBUIZ 2018). Though the use of geoinformation in the HKH region started in the 1990s and while the application areas have been on the rise, the integration of geoinformation into the working of many key governmental agencies has not yet been achieved. The agencies in the region have had limited exposure to the latest developments in geospatial technologies. As the success of any information system depends on its usefulness for the intended target, in the context of the limited resources within the HKH region, it was crucial to understand the needs and priorities of the user agencies before planning to develop such a system.

This present study was commissioned by the SERVIR-HKH program to assess the situation in four countries—Afghanistan, Bangladesh, Nepal, and Pakistan—regarding the decision-making processes at the institutional level (a total of 98 institutions were surveyed) and the capability of the institutions to use geospatial information in an effective manner. The study tried to identify the type of services these agencies provide and the kind of challenges they face regarding data and resources—hardware, software, human; it also attempted to understand the needs that have to be accounted for while producing decision-support products. The study

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_3

aimed to attain threefold objectives. First, to know the institutional structure and policies that provide geospatial- and climate-information services related to agriculture and food security, water resources and hydro-climatic disasters, land cover and land-use changes, as well as on weather and climate. Second, to determine the pattern of use of geospatial tools by the national agencies in decision-support systems and data-sharing mechanisms. Third, to identify potential areas of partnerships with agencies where geospatial applications could be used for providing services to communities/users/beneficiaries so that they are able to address the challenges they face, thereby reducing vulnerabilities and enhancing resilience against disaster.

3.2 The Decision-Making Landscape

A decision-making landscape includes different elements that create an enabling environment for the relevant agencies to deliver services that cater to the welfare of the intended recipient. The decision-making landscape in the government involves knowledge and action, societies, organizations, and individuals (Raadschelders and Whetsell 2017). In this landscape, geospatial technology has the capability of providing valuable tools that can seamlessly organize and analyze knowledge to support evidence-based and spatially-contextualized decisions. In the case of the HKH region, the decision-making processes are generally top-down where national policies define the activity mandates of the specific agencies and then resources are arranged to perform the duties. In order to respond to emergencies, the government usually has standard operating procedures (SOP) which define decision-making processes and the role of individual agencies. As for non-emergency issues such as the monitoring of natural resources, the mandated agencies develop their own priorities and procedures. Thus, in a bid to understand the overall decision-making landscape in the context of geospatial applications, we considered the following elements (Table 3.1).

Different public agencies, sometimes with support from national and international partner organizations, use geospatial tools and techniques to generate data for decision-making purposes. The primary application areas are for: monitoring a situation (e.g., occurrence of a disaster); natural resource appraisal/management and better land-use planning (by way of soil-suitability assessment, urban planning, and land-zoning exercises); forest and biodiversity assessment; and for providing climate services. In this regard, the agencies in the HKH region have been classified into four categories (Fig. 3.1).

Table 3.1 Elements to understand decision-making landscape

Objectives	Elements
To know about institutional structures and policies	• Assess the organogram of the organization concerned to understand the decision-making hierarchy and process • Understand the contexts and contents of decision-making (why decisions are made for short and long terms; and what decision are made) • Understand the decision-making processes during crises and challenging situations
To examine the current pattern of use of geospatial data, tools, and methods	• Analyze the inputs (e.g., data) that organizations use to execute decisions • Examine the level (e.g., local, regional, national) of service delivery for different thematic areas and use data appropriate for that scale • Assess the provisions for data updates
To identify potential areas of partnerships among the relevant agencies	• Study the current partnership process among organizations • Assess the service delivery processes (mapping application, and data dissemination through tables, documents, catalogues, and web portals) • Examine mandates such as the National Spatial Data Infrastructure (NSDI) that aims to facilitate data-sharing provisions among partner agencies

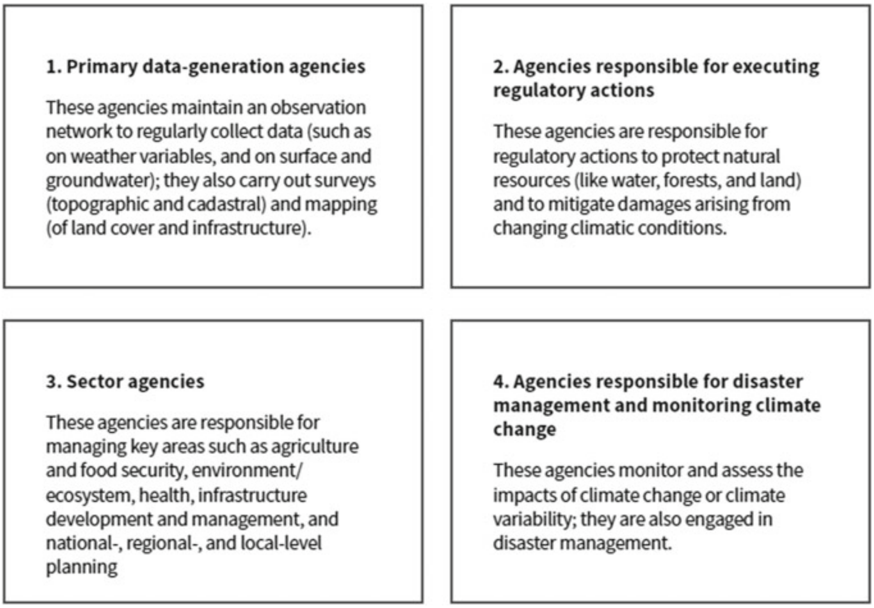

Fig. 3.1 Types of agencies that provide services using geospatial data

3.3 Materials and Methods

The research method had three components to understand the decision-making landscape. The first was a review of literature, mainly organizational reports, government policies, and published literature. The second was a survey of crucial agencies in Afghanistan, Bangladesh, and Nepal using a structured questionnaire to understand the practical realities of the agencies. A total of 98 agencies (15 from Afghanistan, 45 from Bangladesh, and 38 from Nepal) were surveyed for this institutional review (Table 3.2). However, due to logistic difficulties, the questionnaire survey could not be conducted in Pakistan. Thirdly, Key Informant Interviews (KIIs) were conducted with professionals to understand the challenges and to identify the areas of priority for better integration of geospatial applications into the decision-making processes. The combination of these three approaches helped in forming an understanding of the research elements. The literature review gave a broad idea about the historical progress of the decision-making landscape, about governmental policies, and the mandate of different agencies, and the relationship between these agencies. It provided an understanding of policies, procedures, macro-level challenges, and the condition of ICT infrastructure related to geospatial applications. The survey collected information about the capacity of the organizations (in terms of human resources, and hardware, and software) and the current use of geospatial information, and future priorities. The structured interviews became useful tools to collect information on predefined items from the different respondents (Marvasti 2004); these KIIs were aimed at collecting specific information from various organizations regarding their role, data capability, and capacity in terms of human and computing resources. In the first place, the organizations were identified through the literature review. Then the information that was gathered was organized into a database for analysis. A web-based data entry interface was also developed to enter/upload the collected data from the respective countries for compilation, tabulation, and analysis. Table 3.2 lists the number of organizations that were surveyed, country-wise and by themes.

In the particular case of Pakistan, despite it was not being part of the questionnaire survey, the country had always been a significant focus of the

Table 3.2 Number of agencies surveyed by theme and country

Thematic areas	Institutions surveyed in HKH countries (total 98)		
	Afghanistan	Bangladesh	Nepal
Agriculture and food security	3	11	10
Water resources and hydro-climatic disasters	3	12	10
Land cover, land use, and ecosystems	5	11	10
Weather and climate	4	11	08
Total	15 (15.3%)	45 (46.9%)	38 (38.8%)

SERVIR-HKH project. So, in Islamabad, on 23 February 2016, the necessary data were collected through a stakeholder consultation process, jointly organized by ICIMOD and the Pakistan Council of Research in Water Resources (PCRWR). A total of 37 participants attended from 23 agencies and institutions from governmental and non-governmental sectors. The participants were divided into three groups and provided valuable inputs on: the availability of spatial data; the current service delivery processes where geospatial data, methods, techniques are used; and on the skills gaps in the geospatial applications. The participants identified the activities and ranked them on a priority basis. Process documentation was duly done, and a report was generated on the consultation processes. This report was used as a source of data for this research in Pakistan since direct data collection from the institutions was not possible due to logistical reasons.

3.4 Results and Discussions

3.4.1 The Organizational Framework for Geospatial Applications in the HKH Countries

Afghanistan

During the last few decades, several projects have been implemented in Afghanistan to develop geospatial data and spatial data infrastructure. The Afghanistan Information Management Services (AIMS) was established in 1997 to process and disseminate geoinformation and build the capacity of the national agencies in this regard. Till 2009, several geospatial data sets and applications were developed through AIMS. More attempts were undertaken by the United States Geological Survey (USGS), UNDP, and other international organizations to establish a national spatial data infrastructure in the country. However, despite a massive number of projects and initiatives to implement geospatial information, the agencies in Afghanistan showed a limited capacity to develop and maintain geospatial applications. Among the institutions surveyed in Afghanistan was the National Environmental Protection Agency (NEPA), which is primarily responsible for monitoring and managing environmental resources and mainstreaming climate change activities. Then there is the Afghan Meteorological Department (AMD), the principal agency that monitors hydrometeorological variables with an advanced meteorological monitoring network. The Ministry of Agriculture, Irrigation and Livestock (MAIL), is responsible for natural resources exploitation, management, and conservation in the country; it also has a Statistics directorate with GIS facilities with dedicated human resources. Besides, MAIL has a network of stations to collect agrometeorological data for agriculture management. As for the Ministry of Energy and Water (MEW), it is responsible for all hydrological monitoring and water-related disaster monitoring. The Afghanistan National Disaster Management

Authority (ANDMA) has the mandate to deal with the impact of climate change in the country. It is the principal agency that coordinates the development of disaster-warning and disaster-risk reduction systems. On November 6, 2017, the President of Afghanistan endorsed the establishment of the National Geoinformation Center (NGIC) under the National Statistical and Information Authority (NSIA). NGIC (https://nsia.gov.af/) has been given the responsibility to coordinate all geospatial mapping and data management initiatives being carried out by all the relevant agencies aiming to provide coordinated access to all geospatial data. But all said, the Afghanistan experience tells us that the existence of a modest institutional and policy framework to deal with hydrometeorological and environmental challenges is not enough to deliver effective geospatial services. The problems are:

- Decision-making processes are generally top-down; identifying and understanding user needs are usually less prioritized in this region
- National-level decision-making processes generally guide agency-level decision-making activities
- Data-generation and data-sharing provisions are inadequate
- Agencies need skilled human resources and technical support for product/service generation
- There is a need for continued international support to strengthen the capabilities of institutions such as universities in conducting research and providing training as well as in policy analysis in the various disciplines of environmental management
- Agro-meteorological data are available with MAIL, MEW, and AMD; they also collect hydro-meteorological data within their station networks; but the regular maintenance of stations and data management were challenging.

Bangladesh

In Bangladesh, the Space Research and Remote Sensing Organization (SPARRSO) and the Survey of Bangladesh (SoB) are the two mandated government agencies that promote remote-sensing and topographic information systems. A more extensive application of GIS and remote sensing started in the country in 1990 when the Bangladesh Flood Action Plan (FAP 19) set up a GIS facility under the Irrigation Support Project for Asia and the Near East (ISPAN) with funds from USAID. The project later transformed into the Centre for Environmental and Geographic Information Services (CEGIS) as a public trust in 2002. A similar project under the flood action plan responsible for hydrological modeling of flood and cyclone early warning systems transformed into the Institute of Water Modeling (IWM) in 1996. After that, the Local Government Engineering Department (LGED) established a GIS lab for mapping different levels of administrative units (such as thana maps). During the last three decades, many other governmental organizations have been adopting geospatial technology for analysis and spatial data management. In the agriculture and food security area, many of the agencies under the National Agricultural Research System (NARS) went on to establish a geospatial lab. Among them, the Bangladesh Agricultural Research

Centre (BARC), the Soil Resources Development Institute (SRDI), Bangladesh Agriculture Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), and the Department of Agriculture Extension (DAE) have excellent geospatial facilities. In this context, the development of Agro-Ecological Zones (AEZs) by BARC and soil maps by SRDI are the two significant data sets that have been developed, although updating of these data has not happened since its development. In the area of water resources and disaster, in 1998, CEGIS was able to develop a national water resources database for the Water Resources Planning Organization (WARPO); this is a comprehensive database containing most of the spatial data layers of Bangladesh. And since 1997, CEGIS has been using satellite data to monitor flood and erosion. Another critical spatial data are the detailed digital administrative boundary and infrastructure maps developed by LGED, which is used for many spatial applications. In the case of monitoring land-cover changes, it is the Bangladesh Forest Department (BFD) that is in charge. BFD has been producing land-cover maps since the 1990s and recently produced a series of land-cover maps (from 2000 to 2015) through funding from USAID and technical assistance from the Food and Agricultural Organization (FAO).

But while a number of projects have been implemented, funds expended, and data have been generated, the mainstreaming of geospatial technology for various services are still limited in the country. While CEGIS and IWM are maintaining good geospatial capability, the relevant government agencies are suffering from the lack of resources. Lack of coordination among the agencies, use of old data due to the absence of updating facilities, shortage of skilled human resources, ineffective data-sharing provisions, all are significant barriers in better use of geospatial technology in Bangladesh. The major challenges identified by the institutional review carried out in the country are:

- The current geospatial services are useful for short-term decision-making, but not for long-term forecasts by the decision makers
- Data consistency, quality, and outdated data are still concerns for different sectors
- The inadequate number of skilled human resources is a major problem
- Data-sharing provisions are weak among the Bangladeshi agencies and need to be improved because the services developed and provided by many agencies, such as BARC and DAE, depend on the geospatial data produced by other agencies. Any challenges in data sharing jeopardize the whole process
- Early warning facilities are in place for flood, riverbank erosion and cyclone hazards. But the early warning systems for drought, landslides, and thunderstorms are still non-existent.
- Applications of geospatial methods, tools, and data in monitoring and yield forecasting for different crops are very much required.

Nepal

Several agencies in Nepal use geospatial applications for different purposes. The Department of Land Information and Archive of the Government of Nepal is one of the principal agencies that manage land-ownership data for Nepal. The first detailed assessment and mapping of Nepal's land resources were carried out by the Land Resources Mapping Project (LRMP) under the auspices of this agency. The assessment and mapping were based on aerial photography conducted in 1978–79 and were supplemented by extensive field checks and sampling. And, between 1987 and 1998, the Department of Forest Research and Survey, later renamed as Forest Research and Training Centre (FRTC), conducted a nation-wide survey to prepare a National Forest Inventory (NFI). The Survey Department of Nepal has been gathering, managing, and archiving spatial data related to geodesy and preparation of topographic maps. Soil maps of Nepal have been developed for agricultural planning by the Soil Science Division of the Nepal Agricultural Research Council. The Department of Hydrology and Meteorology (DHM), under the Ministry of Energy, Water Resources and Irrigation, has been playing a significant role in generating in situ hydro-met data from a large number of stations; these data are primarily managed using the spatial data structure. Besides, the Central Bureau of Statistics, the Department of Irrigation, and the National Planning Commission of Nepal has been extensively using various kinds of social, economic, and demographic data for national-level planning activities and reporting purposes. On September 20, 2015, Nepal changed its constitution to transform the country into a federal system consisting of seven provinces and 753 local governments (including six metropolitan cities, 11 sub-metropolitan cities, 276 municipalities, and 460 rural municipalities). Many of the tasks, including disaster management, are now being carried out by the provincial governments. However, the spatial data have not yet been updated to reflect the new administrative structure. The responsibility of collecting hydro-meteorological data still lies with the DHM, which is centrally managed. Many international agencies, such as the World Food Programme of the United Nations and the WWF (World Wide Fund for Nature), undertake actions in the country wherein they widely use geospatial data, tools, and applications. The primary data gaps and challenges faced by Nepal are the following:

- There is a necessity to develop accurate baseline data/map on crop types and farming practices at the sub-district (Village Development Committee) level
- The existing spatial data need to be updated to reflect the new administrative changes and the relevant statistical data need to be synchronized with these changes
- There's a need to develop a comprehensive agricultural information system by putting together data in the form of crop statistics, market prices, irrigation systems, soil profiles, disease cycles, etc.
- District-level statistics on disasters (Devkota et al. 2012) are largely not available; this needs to be addressed
- The provision of suitable indices for meteorological drought, agricultural drought, and hydrological drought needs to be developed
- The existing flood risk management practices and the early warning system have to be improved and the lead time increased by using Earth observation applications.

Pakistan

In Pakistan, the geospatial data are mainly produced and disseminated by government agencies as part of their mandated responsibilities (Ali and Ahmad 2013). The primary organizations producing geospatial data and conducting research for the government are the Survey of Pakistan (SoP), the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), the Pakistan Agricultural Research Council (PARC), and the Census Department. Here, it is also important to mention that individual researchers have produced a wealth of information on different themes. The significant area of research by these researchers has been on disaster management—primarily on droughts, floods (Gaurav et al. 2011; Haq et al. 2012), cyclones, earthquakes, and landslides. The researchers have also focused on crop-yield forecasting (Bastiaanssen and Ali 2003) and groundwater use and monitoring in large irrigated areas, especially in Rachna Doab. At the consultation workshop, the experts picked out eight significant areas where geospatial data and techniques are widely used (ICIMOD 2016). These are (i) crop monitoring and yield estimation, (ii) agriculture drought monitoring and forecasting with early warning facility, (iii) catchment monitoring is required for water resources, (iv) rangeland productivity monitoring, (v) monitoring water use for agriculture, (vi) tree plantation monitoring, (vii) development and management of National GIS/RS data bank, (viii) flood forecasting, early warning, and water resources monitoring system. The major challenges with regard to the availability of geospatial data in Pakistan are:

- Geospatial data are collected primarily by government agencies, and data collections are carried out as per the mandates of the respective organizations
- Geospatial data are available for sectors such as agriculture, water resources, land cover, river basins, weather, climate, and environment, but data-sharing provisions among the agencies are generally limited or non-existent
- Regular updating of the data does not happen; lack of skilled human resources is another barrier in advancing geospatial applications.

3.4.2 Institutional Assessment

Since SERVIR's approach depends on partner agencies to deliver the geospatial information services, an assessment of current tasks, priorities, needs, and capacities were essential to understand the overall landscape. This section gives an account of how geospatial technologies are being used by the agencies working in the HKH region; this is based on a specific survey conducted for this study.

3.4.2.1 Major Tasks of the Organizations

The agencies in the HKH region perform different types of activities to deliver information services in related sectors. Among the three countries that were surveyed, it was mostly Nepal's agencies which mentioned that they carried out projects based on the need of the client. Six agencies indicated that they performed assessments using geospatial data, tools, and methods to assess development impacts on the environment and society. The agencies in Bangladesh and Nepal reported that they mainly stuck to the activities that were required to support the core/primary activities of any sector. About 34% of the agencies stated that they used geospatial technologies to address the needs of the users in a more efficient way; 28% indicated that using geospatial technologies helped them to ensure complete coverage of the problem whereby they could use multiple layers of information. Some agencies reported that they used geospatial technologies for better planning and for maintaining commitments in delivering services. The survey results revealed that the agencies prioritized activities in terms of what were most important to them (i.e., primary-focus activities) and then paid attention to secondary/other priority areas. The agencies informed that such prioritization was a tricky and complicated job since it depended on several elements like the duration and size of the project and organizational policy and donor priorities.

3.4.2.2 Requirement and Use of Data

The agencies that were interviewed mentioned about 15 thematic categories (Fig. 3.2), where they use various types of geospatial data and methods. On average, land use and land cover, land topography and elevation, and information about administrative boundaries were mentioned as the most important thematic categories that use geospatial data. The countries, however, provided different accounts in this regard. Most of the agencies in Bangladesh indicated that they needed hydro-climatic data on a daily and weekly basis because they needed to develop early warning forecast products to deal with floods of various kinds (e.g., riverine floods, flash floods, abnormal water surge in the coastal areas) and also to predict related vulnerabilities like riverbank erosion, crop loss, and landslides. The agencies in Nepal mentioned that they needed all kinds of data since the variation in elevation and topography results in significant variation in climatic variables. The agencies in Afghanistan stated that they mostly depended on annual data to produce geospatial products aimed at irrigation planning and also to assess impacts of hazards like drought, floods, and landslides.

Land use and land cover, topography, land elevation, administrative units, and infrastructure are the top five categories of data used by agencies relying on geospatial technologies in Bangladesh, Afghanistan, and Nepal. The agencies indicated during the institutional survey that these data sets helped by way of inputs to undertake different types of analysis and to produce map products, trend

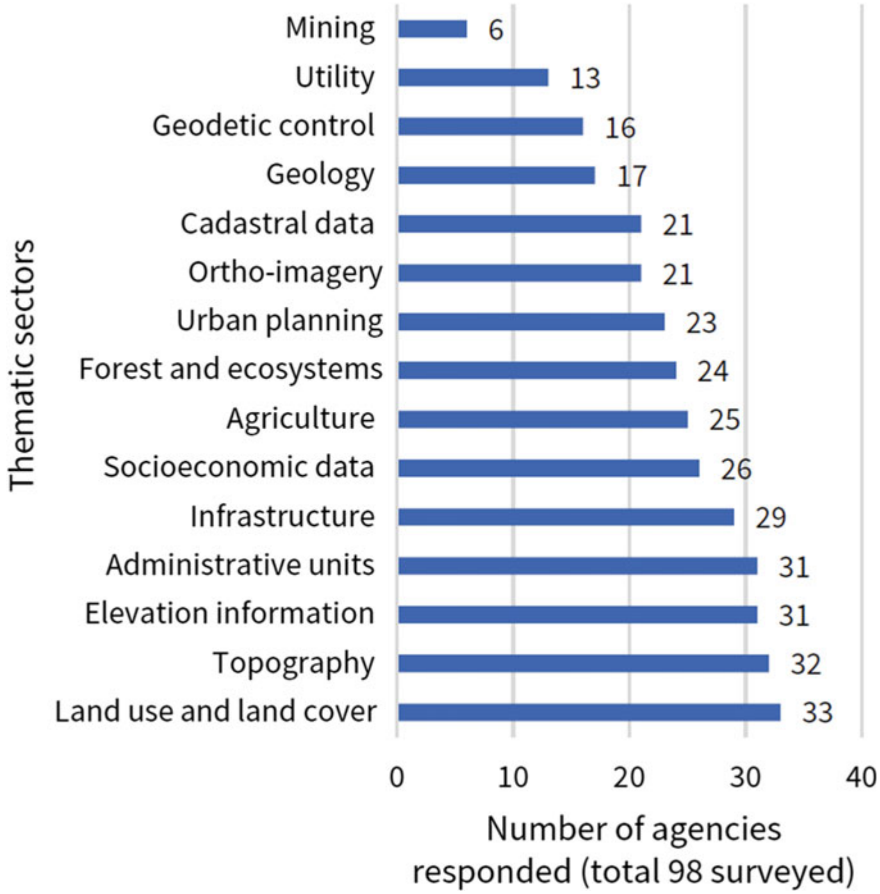

Fig. 3.2 Application areas of geospatial technologies

analyses, impact assessments, and modeling results for the monitoring and planning of resources. The survey also showed that mining and service-utility data were the least used by the agencies in these three countries.

3.4.2.3 Data-Sharing Provisions

The status of exchange and sharing of geospatial data among the agencies are limited in all the countries in the HKH region. These limited sharing provisions exist because of the absence of necessary policy, infrastructure, and resources. For example, in Pakistan, geospatial data are produced and archived by agencies like the Survey of Pakistan, SUPARCO, the Revenue Department, and the Geological Survey of Pakistan; but institutional, legal, and technical arrangements are not in place for coordination among these agencies (Ali 2009). In Bangladesh, the primary agencies that produce, use, and deliver geospatial data are SoB and SPARRSO, which is under the Ministry of Defense. So, for accessing their data, the users have to go through complicated and time-consuming administrative processes and security checks; indeed, items like topographical maps created by SoB still come under the category of classified products and are restricted for public use. Other agencies in Bangladesh, like the Department of Land Records and Survey (DLRS) under the Ministry of Land, the Department of Public Health and Engineering (DPHE), and LGED do use geospatial technologies in different capacities and purposes, but they also need to follow cumbersome administrative processes to share their data with other agencies. Then there's the issue of copyright such as when it comes to reproducing spatial data by digitizing hard-copy maps produced by third parties.

But a few agencies did state that their offices had designated personnel for managing geospatial data sharing with other agencies and that they shared data regularly. Interestingly, Nepal, Pakistan, Afghanistan, and Bangladesh are currently trying to put in place a National Spatial Data Infrastructure (NSDI) so that their central archives are linked to each other, and the dissemination/sharing of spatial data is enabled in an effective manner. Most of the agencies indicated that poor data quality, shortage of human resources, and hardware resources are the major challenges for data sharing.

3.4.3 Institutional Needs and Priorities

The study reveals that though the introduction of geospatial technologies in different application domains started in the HKH region in the 1990s, the proper integration and institutionalization of the system have not yet taken place in the public agencies. While professional activities are taking place, they are by way of time-bound projects where external partner agencies play vital roles in supplying resources and technical solutions. And the funds generally cease with the termination of a project; so, there's no continued support to enable regular operational activities and to update the data/products. In most of the cases, the allocation of resources from the revenue sources is negligible because of the non-existence of policies and strategies in this regard. This uncertainty causes diminishing use/reuse and hampers the sharing of the geoinformation with other agencies. Over time, with the help of partnerships with external agencies when the hardware and software, and EO data become less costly and more available, and the agencies become more familiar with the geospatial tools, methods, and applications, a better ground could be laid for more sustainable and robust use/integration of geospatial technologies in different areas. In this regard, the interviewees had several suggestions (Table 3.3), such as in terms of developing human resources who can better handle geospatial data, tools, and models and where appropriate strategies are in place so that the

Table 3.3 Suggestions for improved geospatial applications

Priority areas	Number and percentage of agencies that responded (multiple responses)
1. Skill development training	32 (21%)
2. Hardware support and upgradation	26 (17%)
3. Necessary fund flow	26 (17%)
4. Retain the trained workforce in the organization	25 (16%)
5. Need appropriate policy (e.g., NSDI)	23 (15%)
6. Access to scale-specific and required data when necessary	20 (13%)

Table 3.4 Country-specific priorities for improving geospatial applications

Priority areas		
Priorities of Nepal	*Priorities of Bangladesh*	*Priorities of Afghanistan*
1. Need appropriate policy 2. Skill development training 3. Hardware support 4. Necessary funding 5. Retain human resources	1. Skill development training 2. Hardware support 3. Necessary funding 4. Retain human resources 5. Access to data	1. Appropriate policy 2. Skill development training 3. Retain human resources 4. Access to data 5. Necessary funding

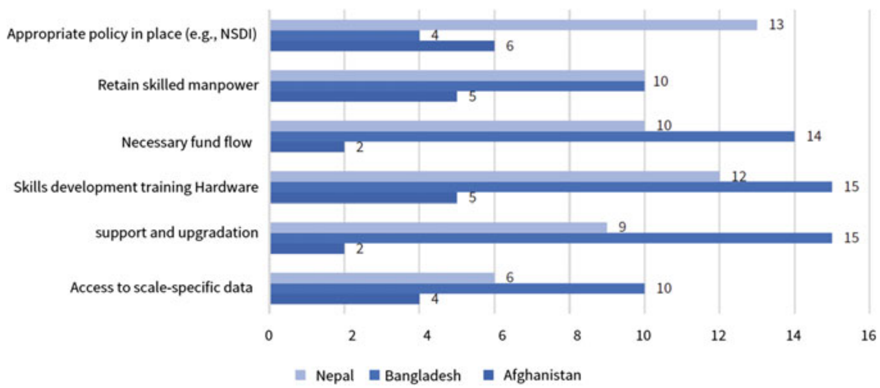

Fig. 3.3 Country-wise priorities for more effective geospatial applications (number of agencies; multiple responses counted)

agencies can retain skilled human resources. However, as Table 3.3 shows, when it comes to priorities of all the countries combined, they are slightly different from the options and priorities of the individual countries (Table 3.4; Fig. 3.3).

3.5 Conclusions and Major Findings

The study on the decision-making landscape of the different countries in the HKH region has provided an in-depth understanding of the degree of applications of geospatial data and tools for various application domains. The study reveals that the introduction of geospatial technologies in different application domains in the HKH region took place in the 1990s. However, proper integration and institutionalization of the system has not yet happened in the case of the public agencies of the region. Activities are taking place only on an ad hoc basis in all the relevant sectors: agriculture and food security; water resources and hydro-climatic disaster management; land cover and land use; ecosystems; and weather and climate. And these activities are mostly time-bound projects where external partner agencies play vital roles in supplying resources and technical solutions. All these resources generally cease with the termination of the contract with the external partners and thus cannot continue providing support to perform regular operational activities and to update the products. The required allocation of resources from the revenue sources is sparse because of the non-existence of policies and budgetary provisions. This lacuna also leaves its impacts on proper use/reuse and the sharing of geoinformation with other agencies.

Agencies in the HKH region are using geospatial technologies within the background contexts mentioned above for improving the services they deliver for user benefits. However, it is important to note that in recent times, the cost of hardware and software has dropped, and EO agencies like NASA have made their data available for free. Against such a backdrop and when the agencies become more familiar with the geospatial tools, methods, and applications, a firmer ground could be laid for more sustainable and robust integration of geospatial technologies with the agencies that are interested in using this technology. In this regard, several recommendations (below) have come from the national agencies that were interviewed for this study; the implementation of these suggestions would go a long way in ensuring a strong foothold for geospatial data infrastructure in the HKH region. It is imperative to mention here that in the given contexts and as an interim solution (unless and until national agencies develop necessary policies), the promotion of online geospatial systems such as Google Earth Engine (GEE) and free software like QGIS could play vital roles because these will help the agencies to avoid the burden of data production and archiving, and also relieve them of the need to procure and maintain expensive hardware facilities. The major findings of this research and the recommendations are grouped into two categories; the first category presents the findings and recommendations relating to geospatial data and applications; while the second category reveals the institutional policy gaps.

Findings on Geospatial Resources (Data, Applications)

- ***Geospatial applications are needed primarily to assess disaster impacts and early warning systems in the HKH region***: The study suggests that the agencies need various types of geospatial data during different time frames –such as daily, seasonal, annual, and decadal—for conducting impact assessments of hydro-climatic disasters (e.g., flood-affected–area mapping in Bangladesh; landslide susceptibility in Nepal—Islam and Sado 2000; Haq et al. 2012; Regmi et al. 2014) and change detection in irrigated agriculture (e.g., in the case of Afghanistan—Haack et al. 1998), as well as for providing early warning and forecasts on droughts and landslides.

- ***National communication reports mention about the need for data and knowledge products***: The governments in their international communication reports (e.g., reports written for UNFCCC, CBD, and UNCTAD) refer to the need for geospatial data for producing high-quality reports with valuable information.

Findings on Institutional Policy Gaps

- ***The apex management of the agencies play important roles in making decisions***: The results suggest that the apex management of an organization plays a vital role in making decisions regarding the integration of geospatial applications in the service-delivery processes. Sensitizing them is, therefore, crucial to incorporate geospatial applications into organizational mandates.
- ***Activity prioritization depends on the core mandates of an agency***: The survey results reveal that agencies prioritize activities as per their organizational mandates wherein there are primary-focus activities and then secondary priority areas.
- ***Time-bound, project-based geospatial applications***: The study findings suggest that in most of the instances, government agencies are approached by international agencies to incorporate geospatial technologies to improve their decision-making and service-delivery processes. These international agencies generally come with geospatial data (where necessary), technical solutions, and the human resources to provide support within a specific period for which they sign the agreement. The geospatial laboratories that are developed during the project time generally lose the necessary attention from the host agency and the apex body of a sector (like ministry) when the project ends. This is mainly because giving importance to such activities are neither indicated in the sector's policy papers nor mentioned in its organizational strategy documents. Therefore, it becomes challenging for the host agencies to sustain skilled human resources and regular updating of geospatial data. There's lack of a recurrent budget from revenue sources for upgradation of hardware and software facilities and archiving and dissemination.
- ***The sharing provisions of geospatial data are poor among the agencies***: Data-sharing provisions are low among the agencies in the HKH region for several reasons. These are: (i) absence of policies, legal frameworks, and mandates; (ii) absence of a central coordinating authority to produce, archive, and share data, not to mention the non-existence of a geospatial data-sharing clearinghouse; (iii) absence of the metadata of the geospatial data in most cases —thus, it becomes difficult to know about the accuracy, consistency, sources,

and scale of the data, resulting in the agencies shying away from receiving the data of other agencies—instead, they prefer to produce the same data again; (iv) limited understanding about the usefulness of sharing geospatial data; and (v), inadequate human and financial resources with the agencies to perform data-sharing activities.

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Chapter 4
A Regional Drought Monitoring and Outlook System for South Asia

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4.1 Introduction

Current observations of the mean rainfall measurements in South Asia have placed in evidence a trend of decreasing monsoonal precipitation in the region (Hijioka et al. 2014). The changing rainfall patterns and their intensity are likely to increase the risk of drought—even during the monsoon period, especially when coupled with other climate-related events (like extreme temperature and winds) that can lead to water shortage and heat stress in the dry season. About 45% of the population (around 800 million people) of the region are now living in areas expected to become climate-stress hotspots under the projected changes in weather conditions. Heat waves are also likely to affect more than 200 million people by the year 2040

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_4

(Mani et al. 2018). Moreover, drought and heat stress are likely to have adverse impact on many of the crops grown in the dry season, which could have negative implications for food and nutrition security for households that are primarily subsistence based. Decreased water availability could also limit agricultural growth unless adaptation measures are implemented (Fig. 4.1). Further, declining snowmelt during spring and summer will likely affect surface water flow and groundwater recharge (due to less snow stored during the wintertime and the current faster rate of snowmelt) and as such, could reduce farm output from irrigable land in the near future. The projected increase in drier conditions will also likely have consequences for farmers relying exclusively on rain-fed agriculture. As variability exists in the South Asian monsoon patterns, droughts are ever likely to take place, thereby adversely affecting food production and agricultural sustainability of countries like Afghanistan, Nepal, Bangladesh, and Pakistan. Drought is a major driver of production risk in rain-fed agriculture in terms of lost yield and income. A major drought can hamper crop yields, force farmers to reduce planted acreage, decrease livestock productivity and can under extreme circumstances affect the price of irrigation water and animal feed (Enenkel et al. 2015; Dorigo et al. 2012; Chen et al. 2014). As water-related food security issues also spawn regional tensions (Bora et al. 2011), an accurate understanding of the availability and variability of water resources, particularly across geopolitical boundaries, is essential for improving food security, economic development, and regional stability. Drought episodes are characterized by an unusual and prolonged period of dry weather leading to situations of water shortage and crop damage. Various causes are at the origin of drought episodes; these can be classified, as done by Wilhite and Glantz (1985), into—meteorological, hydrological, and agricultural (these three are linked to physical situations); and socio-economical (linked to overuse of water by humans for several activities).

Food insecurity in rural areas is caused by biophysical and socioeconomic factors. The former includes climate change and climatic extremes. Food insecurity is also higher in the HKH mountain region than in the downstream plains of South Asia that tend to support more productive agricultural systems (Hussain et al. 2016). In Afghanistan, drought contributed to large losses of the production of maize (85%), potato (50%), wheat (75%), and 60% of overall agricultural production during the extended dry spell between 1998 and 2005 (NEPA 2013). As for Pakistan, situated in the sunny belt of 24°N–37°N latitude and 61°E–75°E longitude, it presents a variability in rainfall across its regions and drought is also a major threat that the country has to contend with (Mazhar et al. 2015; Dahal et al. 2016). Similarly, periodic and brief droughts in Nepal have caused losses in rice and potato yields (Luitel et al. 2015; Alamgir et al. 2015). Moreover, when farmers do not have access to irrigation, like in Bangladesh, they suffer crop losses due to droughts in the monsoon season (Ahmad et al. 2004; PMD 2008). A summary of major drought events that have occurred in Afghanistan, Bangladesh, Nepal, and Pakistan since 1980 is presented in Fig. 4.2.

Fig. 4.1 Farmers in the mountains are heavily dependent on rainwater for agriculture. Photo by Jitendra Raj Bajracharya

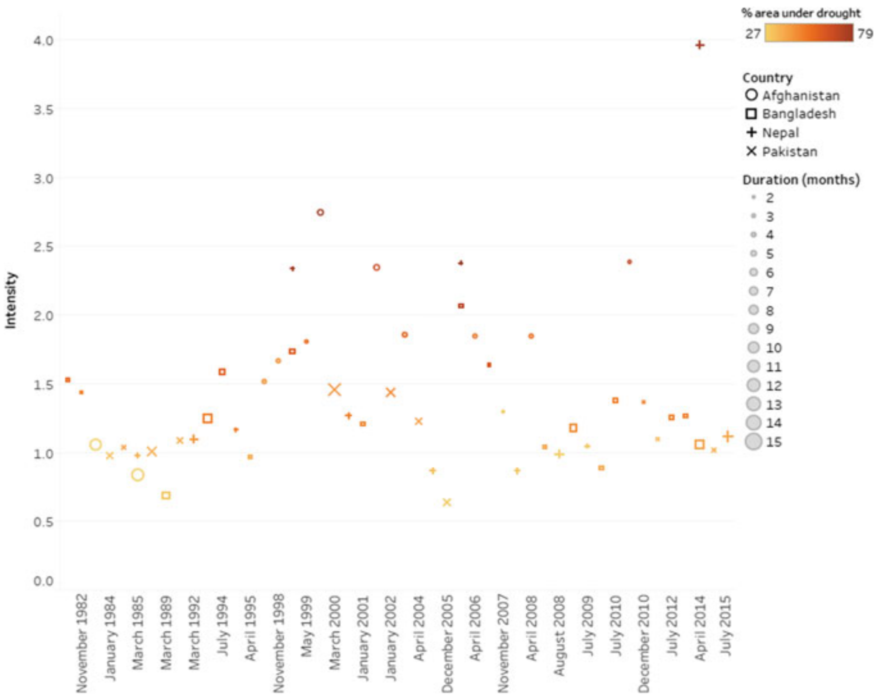

Fig. 4.2 Drought frequency and severity during 1980–2016 in Afghanistan, Bangladesh, Nepal, and Pakistan. (Source: Spinoni et al. 2019)

As is known, drought originates from a deficit in precipitation over a period of time (for a growing season or above), resulting in water shortage for some ecosystem function or societal need (NDMC 2015). Drought may also be defined conceptually and operationally. For example, a definition such as “drought is a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield” (NDMC) is a conceptual definition. While this conceptual definition is important in establishing drought-related policies, the operational definitions are important in measuring the onset, end, and severity of droughts.

Beyond forecasting, the timely detection of onset of droughts is central to local and regional drought-mitigation plans, particularly in the water resources and agriculture sectors. A water resource manager may need information months in advance for resource planning, whereas a farmer may require a few weeks of lead time to take meaningful mitigation actions (Zambrano et al. 2018; Mariano et al. 2018). Early detection can allow farmers and institutional actors to take adaptive measures that include choosing alternative crop-management strategies, giving additional support for irrigation, or increasing insurance coverage. In operational terms, the decision makers need a fundamental understanding of drought-forecast models and products, along with their suitability in time and space, to design mitigation and adaptation strategies.

Recent advances in satellite-based remote sensing have greatly improved our ability to measure some of the key characteristics and impacts of drought, including their effects on food insecurity, human health, and migration. These improvements in drought monitoring can be facilitated by integrating climate, satellite, and biophysical data to extract actionable information for use by the decision makers.

4.1.1 Agriculture Drought Service in the Context of Afghanistan, Bangladesh, Nepal, and Pakistan

Global-scale drought-monitoring activities strengthened in 1980s with the use of RS data from the National Oceanic and Atmospheric Administration’s (NOAA’s) Advanced Very High-Resolution Radiometer (AVHRR). In the South Asian region, capacities in the area of drought monitoring and management are extremely different; they vary across and even within country, from dedicated advance programs for national-level assessments, to farmer-level adaptation policies and practice, to an insignificant formal mechanism for coarser-level assessments at the national level. At present, the drought-monitoring systems in Afghanistan, Bangladesh, Nepal, and Pakistan rely primarily on meteorological station-based assessments, although most station networks are sparse and may suffer from inconsistency in measurements and data quality.

Several countries’ capacity in modeling and forecasting agricultural drought still tend to be limited despite noticeable improvements. So, regional networks on droughts could help strengthen these countries' ability to develop adequate drought-monitoring services and warnings.

In this regard, in the case of South Asia, the South Asian Climate Outlook Forum (SASCOF), established in 2010, is the most prominent platform which functions under the World Meteorological Organization (WMO). Every year during the month of April, SASCOF regional experts review the global and regional climate conditions to produce the monsoon outlook for the upcoming rainy season. The other networks that are partly related to drought monitoring in the region include Global Earth Observation System of Systems (GEOSS) Asian Water Cycle Initiative, South Asian Association for Regional Cooperation (SAARC) Meteorological Research Center, Dhaka, and Global Crop Watch, Beijing. In the case of Pakistan, it is its Meteorological Department's National Drought Monitoring Center (NDMC) that provides drought information and warnings which are primarily based on ground-station data (PMD 2008). However, in the recent years, Pakistan has been able to develop a better and more active meteorological drought-warning system by improving its capability to integrate weather radar and GIS data for drought identification (Islam et al. 2013; Sarkar et al. 2010). Still, the country's prediction level in terms of onset of drought is rather limited (Islam et al. 2013).

In Bangladesh, while the Center for Environmental and Geographical Information System (CEGIS) has developed a Drought Assessment Model (DRAS) that has the capability to monitor agricultural drought and net irrigation (Prasad 2015), it is, however, not yet in operation as it is primarily a research product (Parvin et al. 2015). As for Nepal, there simply is no drought-monitoring system in operation (Abbas et al. 2016). This is despite the fact that an agricultural drought monitoring and warning system has been identified by several studies as crucial for Nepal. These studies include such diverse research projects as: a winter drought-monitoring case study by the Nepal Department of Hydrology and Meteorology (DHM); a governmental project on a crop insurance scheme for farmers; and a study on the use of space technology for drought monitoring and early warning, conducted by the Economic and Social Commission for Asia and the Pacific (ESCAP) (Abbas et al. 2016).

At the global level, there are a number of international agricultural drought-monitoring systems, including Integrated Drought Management supported by the WMO and the Global Water Partnership (GWP), which play a fundamental role in the decision-making processes that govern food aid and agricultural products in the global market. These systems are in operation to assist in: food security and famine early warning; monitoring production to ensure stable global and national markets for agricultural crops; and monitoring and modeling of agricultural land-use change (Hao et al. 2017). But these systems only provide general information at a rather coarse resolution for agriculture in the South Asian countries. There still remain large disparities between the monitoring capabilities of developed and developing nations.

One of the obstacles to the development of an effective and operational drought monitoring and early warning system for the region lies in the lack or absence of a

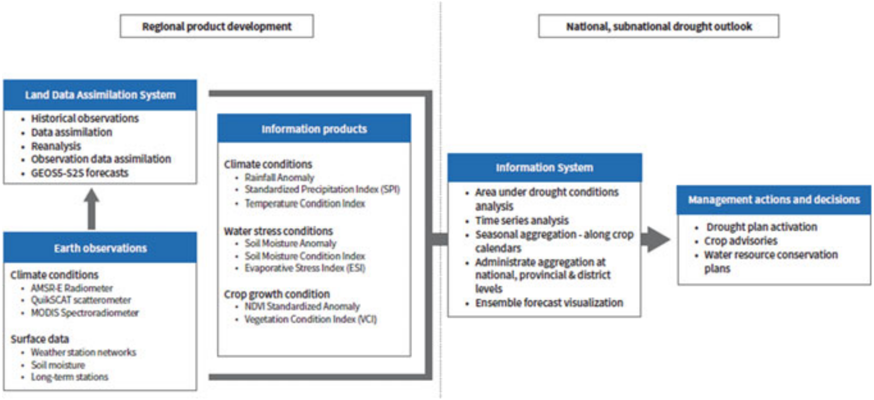

Fig. 4.3 Framework for establishing an integrated platform for drought data products and dissemination service

sufficiently reliable regional hydro-meteorological monitoring system as well as due to data gaps from country to country. To counter these issues, ICIMOD has introduced a Regional Drought Monitoring and Outlook System (RDMOS). The aim of the service is to produce a reliable drought indicator for countries in the HKH region. In this system, the drought and vegetation indices are based on climatic models, EO data as well as land-surface models to produce a mechanism whereby drought is monitored in a near-real-time span. It also provides a seasonal outlook, every four months, in order to help the countries of the HKH region be better prepared to take drought management actions.

In this regard, a twofold framework has been developed based on the goal of establishing an integrated modeling platform to produce scientifically robust regional-level drought data products and the development of appropriate information systems to contextualize data and support related decision-making by key institutions working on climate adaptation (Fig. 4.3). The system has two distinct components, one of monitoring the current drought conditions and the other of framing a seasonal drought outlook, ranging from four to nine months. Thus, the system gives prominence to both the quality of meteorological forecast and the accuracy of the modeled initial hydrological state, particularly during the early period of prediction.

4.1.2 Indicators for Operational Drought Monitoring

In order to provide a quantitative measure of the main episodic characteristics of a drought, data are assimilated from several variables, like precipitation and evapotranspiration, to build drought indices. A drought index can be used to quantify moisture conditions in a particular location, and thereby identify the onset and intensity of a particular drought event. However, as a drought may involve various characteristics, an efficient drought-monitoring system must take into account the type and characteristics of the event. Therefore, several drought indices have been derived for the effective monitoring of the intensity, duration, severity, and spatial extent during the various stages of a drought (WMO and GWP 2016; Mishra and Singh 2010). In this regard, as part of our co-development philosophy, several consultation workshops were held with the key collaborators with the aim to generate agreement on the relevant drought indices that can be suitable for national and regional operational needs. Currently, four key variables related to drought indices are being used by the RDMOS: the Standardized Precipitation Index (SPI); the Evapotranspiration Deficit Index (ETDI); Soil Moisture Anomaly (SMA); and the Vegetation Conditions Anomaly (VCA). These methodologies and the input data are discussed below. While the methodology to compute the drought indices tends to be the same globally, the input data may vary across regions. A more harmonized and standardized set of indices can help in getting better information on the main causes of drought (Steinemann and Cavalcanti 2006).

Standardized Precipitation Index (SPI): SPI is the most notably used indicator for drought detection and monitoring. It is based on a statistical comparison of the total amount of precipitation received by a region for a specific period of time and provides long-term trends for a specified period of the year. It is generally calculated on the basis of monthly intervals for a moving window of *n* months, typically 1, 3, 6, and 12 months.

Evapotranspiration Deficit Index (ETDI): A useful tool to monitor short-term agriculture drought, the ETDI, alongside the Soil Moisture Anomaly, provides information on the actual evapotranspiration as compared to crop evapotranspiration. This water stress ratio can be compared with the median water stress ratio obtained from longer-time framework observations.

Soil Moisture Anomaly (SMA): Agricultural drought is characterized by soil moisture deficiency that can adversely impact crop yield and production. SMA is the main instrument used to measure soil moisture content and to identify potential agricultural drought episodes. Soil moisture is an important component of the hydrological cycle, and its evaluation is critical in forecasting the changes in the water balance of a region. In an agricultural system, the spatial variability of soil moisture and its deficits may result in a decline in crop yields or in the variability in yields.

Vegetation Conditions Anomaly: This indicator measures the anomalies of satellite-measured normalized difference vegetation index (NDVI) and is used to highlight areas of relative vegetational stress during agricultural drought. For large-area monitoring, season-integrated NDVI offers an effective approach to measure crop production as it closely relates to the overall plant vigor, canopy expansion, and water stress during the season of growing.

4.1.3 Assembling Land Data Assimilation System

The NASA Land Information System (LIS) is a widely used, open-source land-surface modeling, and data assimilation infrastructure developed by the Hydrological Sciences Lab at NASA Goddard Space Flight Center (Kumar et al. 2006). The original goal of LIS was to enable flexible and high-resolution land-surface modeling at the same spatial and temporal scales as RS measurements. From the LIS, other systems were developed such as the Land Data Assimilation System (LDAS), a land-surface modeling software for specific purpose and domain. LDAS is based on the merging of standard, ground-based observation, and satellite observation with a numerical model to obtain an accurate estimate of the land-surface state. Models suffer from errors due to limitations in the structure, imperfect input data sets, and parameter uncertainty, while observational data sets are generally incomplete in space or time, capture only select aspects of the hydrological cycle, have limited predictive potential, or are subject to their own measurement errors. Acknowledging these limitations but also recognizing the tremendous information content in today's observation systems and advanced land-surface models, LDAS merges models with observation data sets using statistical algorithms that weigh inputs according to their relative uncertainty. In practice, this means that LDAS makes use of the best available input data, including information on meteorology and landscape (in terms of soil, topography, land cover, etc.), applies these inputs to drive an ensemble of land-surface model simulations, and then periodically applies updated observations of the modeled variables (in terms of soil moisture, snow cover, etc.) to nudge the model toward the observed conditions.

The South Asia Land Data Assimilation System (SALDAS) is a collaborative modeling initiative that is representative of these efforts. SALDAS employs the Noah-MP land-surface model at a 5-km resolution with input meteorology from MERRA2, GDAS, and Climate Hazards Group InfraRed Precipitation estimates (CHIRP) (Funk et al. 2015) in a monitoring mode as well as from the downscaled Goddard Earth Observing System model (GEOS5v2; Rienecker et al. 2008) surface fields in a forecast mode. SALDAS also includes the simulation of the processes of irrigation and groundwater withdrawal (Nie et al. 2018), including some data assimilation capabilities (Fig. 4.4).

4.1.4 Evaluation of Satellite Precipitation Estimates

In the case of process-based hydrological simulations and forecasts, accurate meteorological estimates are critical. But the mountainous regions of South Asia have limited in situ meteorological stations and river-discharge measurements. In this situation, RS and model-derived meteorological estimates are the useful inputs for distributing hydrological analysis.

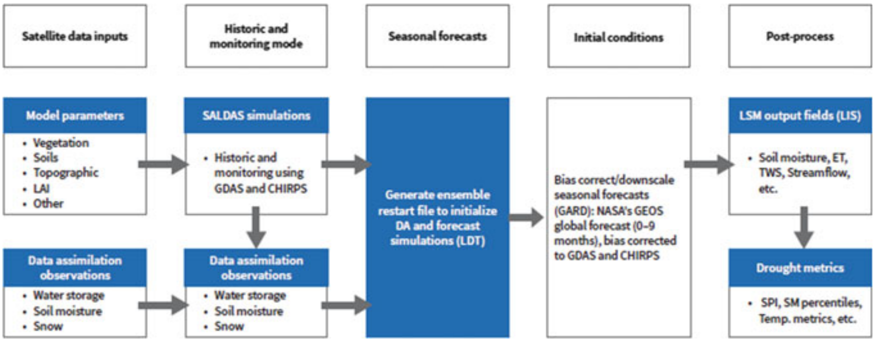

Fig. 4.4 Elements and process of the SALDAS system for producing drought data products

Among the available satellite precipitation data products, the long-term CHIRP is available at a high spatial and temporal resolution and can provide an opportunity to develop drought monitoring and early warning applications in data-sparse regions using rainfall estimates. However, CHIRP data also have some level of uncertainty, which could affect the accuracy of predictions when they are used in a drought outlook scenario.

In the case of precipitation data products, they are being tested in different time frames in different regions of the world that represent different climate conditions. To proceed with this evaluation, various statistical metrics like the root-mean-square error (RMSE) and the bias and regression correlation coefficient of determination (R^2) are used (Habib et al. 2009; Jiang et al. 2012; Nelson 2016). But in South Asia, such information is difficult to validate on account of limited access to meteorological station data. In this evaluation, we compared the monthly precipitation estimates, during 1980–2018, from CHIRP with APHRODITE and the data from 130 rain gauges collected from Bangladesh, Nepal, and Pakistan that represent seven key climate divisions of South Asia (Fig. 4.5). The performance of the precipitation products was evaluated by using continuous (ME, MAE, and R^2) and categorical (PBIAS, RSR) statistical approaches (Fig. 4.6). These metrics are based on a pair-wise comparison to evaluate the performance of the monthly CHIRPS-2.0 product, which estimates the amount of rainfall on each rain gauge and then is summarized for each climate division. Overall, CHIRP performs better in wet regions than in arid and semiarid areas, and achieves greater accuracy during summer than in winter.

4.1.5 Season to Sub-season (S2S) Forecasting

Monsoon prediction is a key element in water-related agricultural management and disaster preparedness. However, being able to forecast the monsoon dynamic has

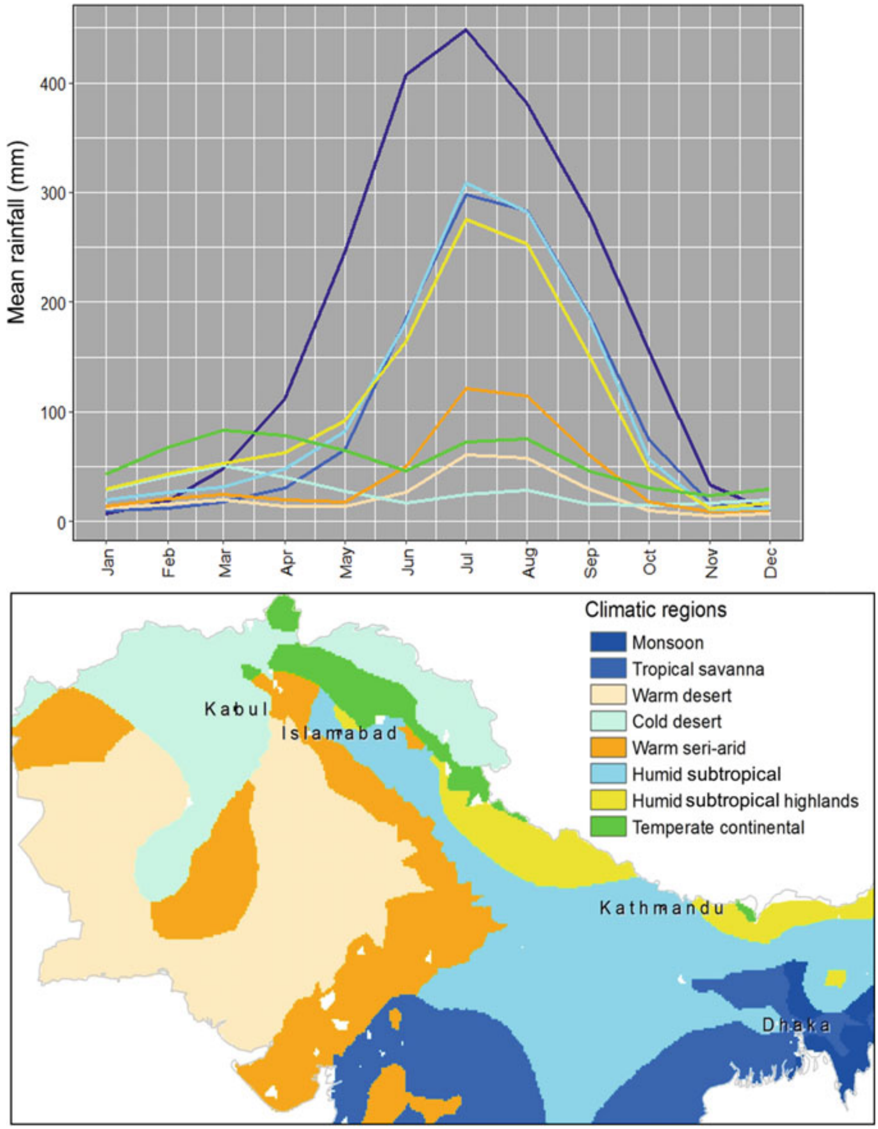

Fig. 4.5 Climatic regions of the northern portion of South Asia

proven to be a difficult exercise. The current development in the S2S meteorological forecast as well as improvements in EO applications could be exploited to provide a more accurate monitoring of the hydrological states and thus better forecasting. The information from these sources is currently being merged in the S2S Land Data Assimilation System (S2S-LDAS) (Yifan et al. 2020).

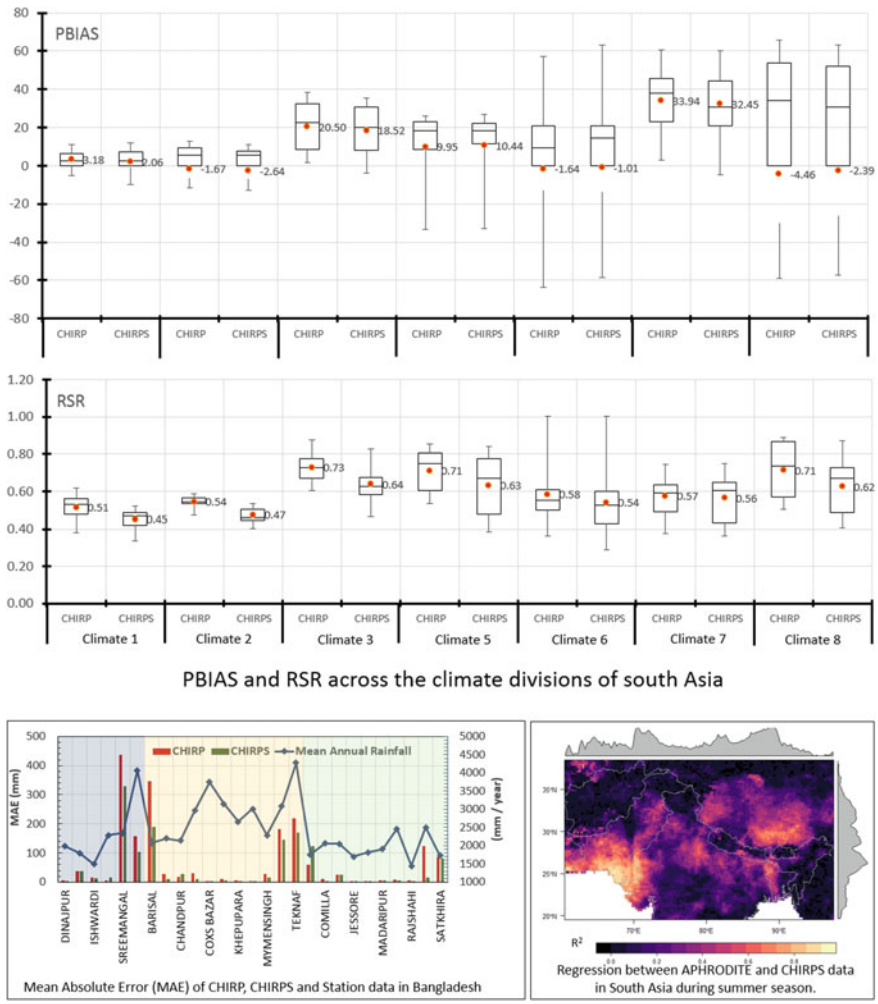

Fig. 4.6 Key results of the satellite-based precipitation estimates

The SALDAS S2S system merges models with satellite observations to optimize forecasts on initial conditions, downscale forecast meteorology, and to forecast hydrological water fluxes. SALDAS runs in the S2S forecast mode once every month. The system reads in the GEOS5v2 forecast ensemble, downscales using the Generalized Analog and Regression Downscaling (GARD) (Gutmann et al. 2017) technique, and runs Noah-MP forward with the forcing, using the SALDAS monitoring system to provide the initial surface-state conditions. While the HKH-S2S simulations are performed at 5-km resolution, the forecasts of meteorology and hydrology are presented through interactive applications that offer users access to the ensemble mean, to the output of each ensemble member, and to

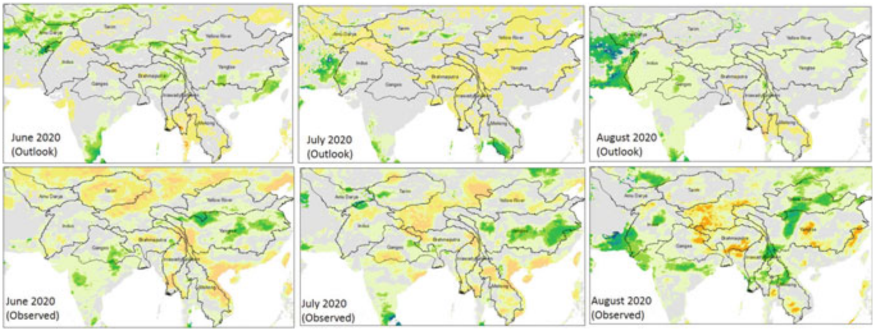

Fig. 4.7 Regional seasonal outlook for precipitation based on the initial condition in April–May 2020 and comparison with the conditions observed by the CHIRPS data set

ensemble statistics presented as ranked anomalies. In keeping with the S2S target-time horizon of the system, the outputs are presented as temporal averages at decadal and monthly resolutions. The evaluation of the system is being conducted by comparing on-ground data with satellite observation data for the water fluxes. It is expected, that in principle, better sub-seasonal hydrological forecast would be of great use for governmental and other organizations in better assessing the risk of drought and taking mitigating actions. In the month of May 2019, the first seasonal forecast was produced for the 2019 monsoon season and the results were shared with relevant professionals from meteorological and agricultural institutions, including the Nepal PPCR program agriculture advisory team. Similarly in 2020, the seasonal outlook was produced in May 2020 and Fig. 4.7 shows the results of the months of June, July, August and its comparison with the observed conditions measured by CHIRPS data sets the end of the season. The analysis of the match and mismatch between the predicted and observed conditions has helped in gaining the initial confidence of users.

4.1.6 Information System Development

Efficient and effective water-related information systems should be able to house different aspects like climate parameters and water, soil, and socioeconomic indicators which clearly identify the key characteristics of the severity of a drought, its geographical extent, and its impacts (WMO 2006). Additionally, the delivered information via the warning system should be formulated in a manner that is clear and easy to understand in order to not exclude its use by non-specialist decision makers.

The purpose of a viable information system should not be limited to making data accessible, but it should also pay attention to the target audience and the intended support for decision-making. The United Nations International Strategy for Disaster

Reduction (UNISDR 2006) suggests that early warning systems must be location specific and people centered while integrating four elements: monitoring and early warning service; providing information on the risks faced; disseminating easily understandable warnings to those at risk; and awareness and preparedness to act. In accordance with these key principles, discussions were held with the key users. The consultations highlighted the need for data analysis at two levels: first, at the basin level to understand the general patterns, irrespective of administrative boundaries—this mainly focused on water-management decisions; and second, at the district level to support local-level actions.

As it is known, any web-based data analysis system includes front-end clients, application services, and back-end data repositories. So, to facilitate the implementation of these components, information on functional requirements were gathered and a statistical analysis of the needs was identified. The Tethys platform used for the application services contained open-source software selected with the aim of addressing the particular needs of web applications related to water resources. The web application was developed using the Python software development kit. Additionally, the Tethys platform was supported by the Django Python web framework, thereby offering a strong web foundation with high performance and security (Fig. 4.8).

The Regional Drought Outlook System also provides the means to visualize seasonal outlook anomalies at the basin level. An average of seven ensembles is regarded as defaults, while the user can select individual ensembles as well.

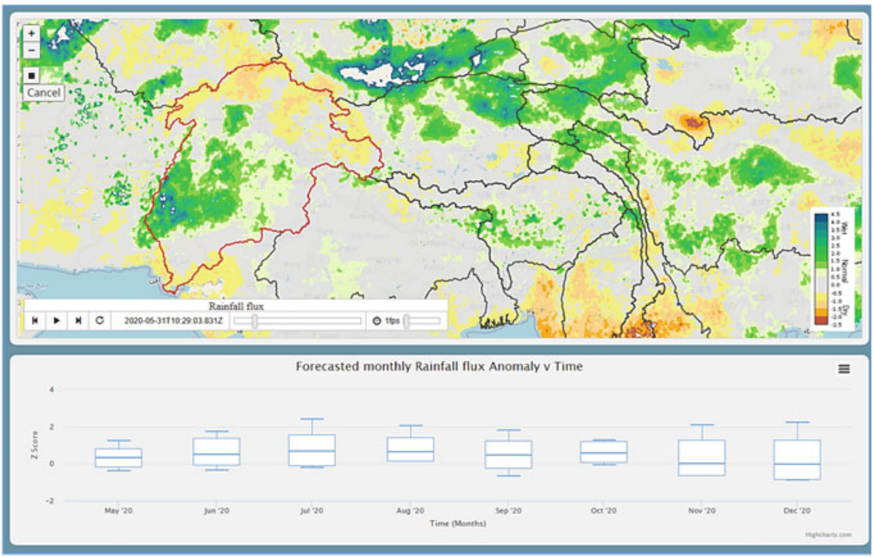

Fig. 4.8 Interface of the regional drought outlook system (http://tethys.icimod.org/apps/regionaldrought/)

Similarly, the drought indicators and the basin can also be selected interactively by the users.

In the national and subnational contexts, while agricultural practitioners have knowledge about agro-meteorology, it is usually cumbersome to perform climate data analysis in a particular area. So, to facilitate the process of data analysis and aggregation, a user-friendly system was developed for the four target countries as a "National Agricultural Drought Watch" in close consultation with the key national stakeholders and the user community. The convenience in use of the system could aid in increased use of the related data products for practical decision-making. Meanwhile, an orientation workshop on the usability of the system was also held. At this point of time, the system is being adopted by the user community for regular use in their decision-making process.

The National Agricultural Drought Watch provides interactive maps of administrative units, as also near-real-time graphs of rainfall, evapotranspiration, soil moisture, and temperature. Additionally, a specific seasonal assessment window provides a systematic way for users to complete a seasonal aggregated assessment where the user can choose an administrative boundary and the time period of assessment according to a crop calendar.

The four bar graphs in Fig. 4.9 represent the aggregated assessment in terms of the percentage of areas under conditions between −2 to +2 based on the standard anomaly calculation of rainfall, soil moisture, evapotranspiration, and temperature. All the calculations are masked to display only the cropped areas. The percentages in the normal graph represent the conditions aggregated for an entire selected administrative boundary.

After the formal launching of the drought outlook service in July 2019, the major focus has been on the adoption of the system by the partner agencies in Afghanistan, Bangladesh, Nepal, and Pakistan. The National Agriculture Management Information System (NAMIS) of Nepal is utilizing the drought watch

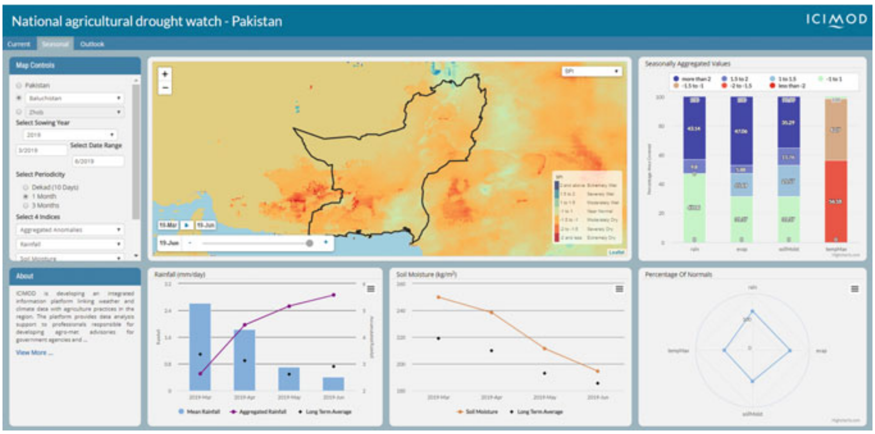

Fig. 4.9 National agricultural drought watch interface (http://tethys.icimod.org/apps/droughtpk)

service to disseminate information on the drought conditions and outlook among the stakeholders in the country, while the World Food Programme of Nepal is utilizing the drought data products in their quarterly food security assessments. Besides, building on SERVIR agriculture drought products and learning, the Climate Service Initiative of ICIMOD is establishing a localized agriculture advisory in Nepal's Chitwan District.

In the case of Bangladesh, the Bangladesh Agriculture Research Council (BARC) is working toward hosting the drought outlook system. Similarly, the Pakistan Agriculture Research Council (PARC) is in the process of establishing an Agriculture Decision Dashboard under the Ministry of Food Security and Research for planning decisions on food security which will also incorporate SERVIR's seasonally aggregated drought data products.

4.1.7 Trainings and Capacity Building

A well-structured and rigorous effort has been made in the institutional capacity building of the national agriculture agencies in Afghanistan, Bangladesh, Nepal, and Pakistan. A comprehensive resource book has been prepared which has both theoretical and practical information on the drought monitoring and forecast approach adopted under the RDMOS by the four countries (Qamer et al. 2019a, b). Several training exercises have also been conducted, including regional, national, and on-the-job trainings where a good number of professionals were exposed to drought-monitoring issues.

In this regard, the Regional Knowledge Forum on Drought held at ICIMOD from 8 to 10 October 2018 brought together 100 participants—academicians, policy practitioners, researchers, and media persons—affiliated to 50 institutions based in 13 countries in Asia and beyond. The forum discussed the ways to establish a regional partnership through the participation of national and regional institutions, the private sector, and local and international organizations to improve climate services using EO applications and thereby facilitating agricultural decision-making that can strengthen the food security situation in the region (Qamer et al. 2019a, b). Discussing examples from South and Southeast Asia, the panelists showcased the value that EO technologies and climate services can bring to establish national and regional drought monitoring and early warning systems, as well as agro-advisory services.

4.1.8 Leanings and Future Directions

In South Asia, only a few scientific resources are available on operational drought services and associated mitigation tools. The establishment of the RDMOS provides support for drought assessment and mitigation in South Asia. The system produces key drought indicators including at decadal, monthly, and trimonthly intervals and is equipped with the ability to analyze these indicators on a seasonal scale according to crop calendars or the period of interest of the users. Besides, meteorological and hydrological forecasts are presented through interactive applications that offer users access to the ensemble mean, to the output of each ensemble member, and to ensemble statistics presented as ranked anomalies. In keeping with the S2S target-time horizon of the system, the outputs are presented as temporal averages at decadal and monthly resolutions. In addition, the system produces seasonal forecasts on precipitation, soil moisture, evapotranspiration, and temperature to evaluate potential drought hazards. The program has also developed operational agriculture-monitoring data products and dissemination platforms through its network of partners in NASA, USAID, CIMMYT (International Maize and Wheat Improvement Center), and globally renowned universities, as well as in close collaboration with national experts from Afghanistan, Bangladesh, Nepal, and Pakistan.

To enhance the usability of these platforms, extensive capacity building efforts have taken place to promote the use of EO data among the national-level managers, relevant development partners as well as field-level agriculture extension professionals. As an operational service, it is expected to reduce regional crop loss caused by drought-associated damage. The advisory support system, over time, is expected to achieve impacts by catalyzing and supporting the processes of innovation through two pathways: acquisition of new knowledge; and capacity building of individuals and institutions. The knowledge pathway is anticipated to facilitate and support stakeholders in gaining better access to the necessary products for the smooth running of the service. The second pathway of capacity building has been designed to enable individuals and institutions to generate and use EO and GIS information to develop advisories relevant at the farm level. The gradual uptake of the service is under way via trainings of partner agencies in Afghanistan, Bangladesh, Nepal, and Pakistan.

The current system provides analysis at the district level and is a guide to any emerging agricultural drought situation. However, systems with higher resolutions will be needed in the future, as most agricultural decision makers require more localized information. The linkages between community-based adaptation approaches and the national early warning systems are still very weak (Pulwarty and Verdin 2013), and this can only be improved by roping in the expertise of agricultural extension professionals.

Drought-warning systems provide excellent means of alleviating the issue of short-term food insecurity and thereby save lives. But the current crisis management approach has several limitations. A paradigm shift to proactive approaches based on the edifice of drought-risk reduction and building greater societal resilience to drought impacts is the need of the moment. This calls for improving long-term agricultural land use and efficient water resource planning based on quantitative resource assessments. In this region, China is already moving from a drought-emergency response (reactive) approach to a drought-risk management (proactive) approach, which involves integrated systems of monitoring, prediction, and modeling of hydrological and meteorological influences on water resources, coupled with demand management for water conservation. Agricultural drought monitoring and other early warning systems can be useful only to the extent that they offer actionable information that can be used to avoid or minimize the economic and social impacts of the predicted risk (Tadesse et al. 2018). This strategy should also take into consideration the drought impacts on health which involve the vulnerability of the people living in drought-prone areas. Such a scheme of things could help build a more drought-resilient society (Li et al. 2017; Wall and Hayes 2016). And it goes without saying that to mitigate the impacts of drought on human life and the environment, and to ensure production of adequate food to avoid food crises, developing strong early warning and mitigation strategies are critical (Zambrano et al. 2018; Mariano et al. 2018).

As part of climate adaptation strategies, crop insurance programs could aid in buffering the financial impacts of drought-induced crop failure. However, the implementation of index-based crop insurance in South Asia is rather constrained due to the sparse hydro-meteorological network in the region and due to high variability in the agro-meteorological conditions stemming from the complexity of the terrain (World Bank 2009; USAID 2014). In such a context, locally calibrated RDMOS can play a supporting role in implementing crop insurance as well as forecast-based financing in the agriculture sector.

Currently in South Asia, crop yield assessment is largely done through crop-cut surveys, which are time-consuming and expensive. The integration of process-based crop models with the current SALDAS system could also potentially improve efficiency in crop monitoring, but more research is required in this area (Xia et al. 2019).

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Chapter 5
In-Season Crop-Area Mapping for Wheat and Rice in Afghanistan and Bangladesh

Varun Tiwari, Faisal Mueen Qamer, Mir A. Matin, Walter Lee Ellenburg, Waheedullah Yousafi, and Mustafa Kamal

5.1 Introduction

Cereal grains are the most commonly grown crops in the world. Wheat and rice are important commodities which contribute to 50% of the world's food-calorie intake (McKevith 2004). These two cereals are critical to food security in the developing regions. In this context, crop-mapping services can be used for detailed monitoring of the cultivated areas; it can also provide the area statistics of specific crops and the data on their intensity across the landscape. This mapping process is also valuable for government agencies since it provides them with critical information that can be used to manage their stocks (for imports and exports). This chapter dwells on a crop-mapping service developed under the SERVIR-HKH program. In this regard, the needs assessment was carried out with the assistance of the governments of Bangladesh and Afghanistan through a consultation workshop. Wheat mapping in Afghanistan and rice mapping in Bangladesh were the top priorities for the respective governments. Here, we discuss two particular mapping exercises that were undertaken in these two countries: wheat mapping in Afghanistan at a national level and the mapping of Boro rice in selected districts of Bangladesh.

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
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5.1.1 Cereal Crop Production and Food Insecurity

In-season mapping of major crops is important for early assessment of production and to know about any potential threats to food security. As all of us know, South Asia is the most populated part of the world, wherein recent years, both industrialization and urbanization have grown by leaps and bounds. This has created an imbalance in food supply and demand in the region. While it is true that more land came under agricultural activity from the 1960s to 2000s, resulting in an increase in food production (Ramankutty et al. 2018). In recent times, it has been observed that the production levels have gone down because, increasingly, agricultural land is housing urban infrastructure. Another reason for the dip in food production is that conventional methods are still being used for agricultural land management. Then there is the factor of monsoonal variability due to changing climatic conditions which has also affected crop production. The other factors are poor quality of seeds, small farms that have limited or no access to technology, and natural disasters in the form of floods and even earthquakes.

The decrease in domestic crop production and the yearly fluctuations in the same pose serious threats to the food security situation in the HKH region. Thus, swift and accurate estimation of crop production becomes vital in providing a baseline for formulation and implementation of policy related to agriculture management at the national level. This also plays a significant role in the planning and decision-making processes related to food and social security (Demeke et al. 2016).

5.1.2 Crop Dynamics in Afghanistan and Bangladesh

Figure 5.1a,b shows the bioclimatic zones—a proxy for agro-ecological zones (AEZs)—of Afghanistan and Bangladesh (Balasubramanian 2011). AEZs are areas with similar climates, vegetation, and soils. Some examples are deserts, savannas, tropical forests, steppes, temperate forests, and cold regions. These zones are developed utilizing different parameters such as elevation, climatic conditions, and soil and vegetation types. Agricultural activity is closely related to the conditions of these zones. The sowing, growing, and harvest time of crops are dependent on the conditions and varies from one AEZ to another. Broadly, there are five AEZs in Afghanistan and two in Bangladesh. This is mainly because of the diverse topography and climatology in Afghanistan as compared to those in Bangladesh. However, at the micro-level, there may be many AEZs because of diverse geography, with thousands of microclimates and micro-watersheds, as conditions frequently change from one valley to the next, within a fairly short distance.

The phenology of a crop is referred to as the periodic life cycle events of plant growth and how these are influenced by seasonal and inter-annual variations in climate (Martínez and Gilabert 2009). Crop phenology plays an important role in understanding the dynamic vegetation-growth patterns in a crop (Fisher and

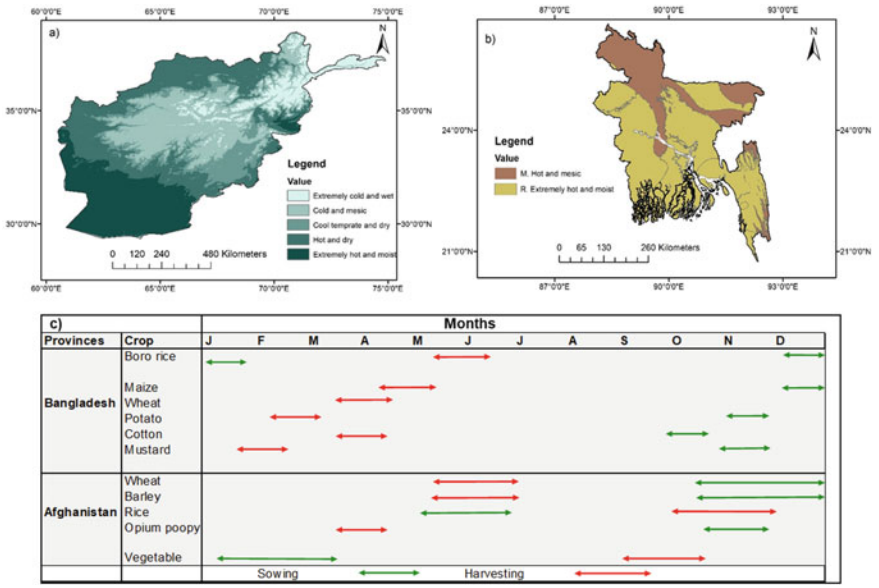

Fig. 5.1 **a** AEZ of Afghanistan; **b** AEZ of Bangladesh; **c** Crop calendar

Mustard 2007; Myneni et al. 1997). The vegetation indices derived using satellite images help in studying the phenology of a crop at different stages (Ahl et al. 2006); these indices are normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and a two-band enhanced vegetation index (Zhang et al. 2014; Piao et al. 2006; White et al. 1997; Zhang et al. 2003). For crop mapping using EO technology, information on the growing season of crops is critically important as this enables the construction of a phenological profile for the crops.

Information on the growing season of a crop can be derived using a crop calendar. A crop calendar for an AEZ or province provides information on the planting, sowing, and harvesting periods of the crops in that zone. Figure 5.1c depicts generalized crop calendars for Afghanistan and Bangladesh. While such generalized calendars provide useful information, RS-based crop mapping requires a crop calendar at the AEZ or province level. For this study, the crop calendars—of provinces or districts—were provided by the Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) and by the Bangladesh Agriculture Research Council (BARC). These calendars were utilized as a starting point to determine the timing of the phenological stages of wheat (in the case of Afghanistan) and Boro rice (in the case of Bangladesh), and then satellite images were used for a more comprehensive study.

5.1.3 Wheat Crop in Afghanistan and Recent Efforts in Mapping

The agricultural sector plays a significant role in Afghanistan, providing revenue for nearly three-quarter of the country's population. It contributes nearly 28% to the country's GDP (United Nations 2013). Wheat is the primary crop and food of Afghanistan and is grown in every province of the country; and mostly, it is grown for self-consumption. That said, its production has not yet been able to meet the internal demand. Figure 5.2 depicts the import of wheat to Afghanistan during 1960–2019. It can be observed that wheat imports have consistently increased in the past few years. In recent times, about 1 million ton (equivalent to 25% of the internal demand) of wheat have been imported annually to meet the internal requirement (Martínez and Gilabert 2009), making Afghanistan one of the leading importers of wheat in the world (Persaud 2013).

The government utilizes the statistics on wheat—about the areas where it is grown and how much is produced—to assess the current demand and also for procurement in case of shortages. However, limited work has been done till now in the case of wheat-area estimation in Afghanistan. While MAIL carries out yearly qualitative assessments of wheat-sown areas using ground sample data and with the help of some conventional RS techniques based on interpretation of satellite images

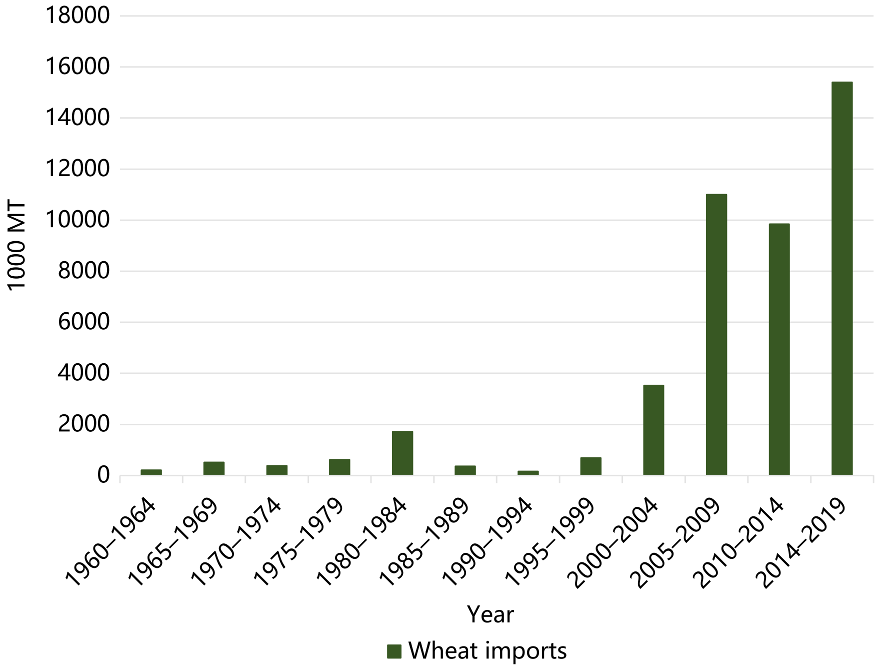

Fig. 5.2 Wheat import data of Afghanistan. *Source* USDA

(FAO 2016), United States Department of Agriculture (USDA) has made some qualitative assessments using NDVI anomalies (Baker 2015; Pervez et al. 2014).

Recently, donor agencies such as United States Agency for International Development (USAID) have shown interest in food security management in Afghanistan. They have started projects like grain research and innovation (GRAIN) which primarily supports wheat-related research in order to boost production; the project also works on resilience building and diversification. Then, there is the Kandahar food zone (KFZ) project which focuses on strengthening rural livelihoods (USAID 2017). However, currently, there is no operational framework in Afghanistan that can provide a rapid assessment of wheat-sown areas essential in terms of food security management.

5.1.4 Rice Crop in Bangladesh and Recent Efforts in Mapping

The economic growth of Bangladesh depends highly on agriculture. Two-third of the labor forces in the country are either directly or indirectly employed in the agricultural sector (Raihan 2011). Moreover, nearly 80% of the population belong to rural areas which directly rely on the agricultural sector for their livelihood. And, agricultural production accounts for one-third of the country's GDP and 32% of its value of exports (Rahman and Hossain 2014).

Rice is the most valuable commodity in the economy of Bangladesh. It is the most dominating cereal crop, making Bangladesh the world's sixth-largest producer of rice. This also makes Bangladesh one of the top exporters of rice in the world. However, it is becoming increasingly evident that the production of rice can be extremely vulnerable to the impacts of climate change (Aryal et al. 2019). Rice production has been adversely influenced by unpredictable rainfall, temperature extremes, increased salinity, droughts, floods, river erosion, and tropical storms. Moreover, the prediction is that these events would be highly repetitive and intensify in the future (Sivakumar and Stefanski 2010), which could lead to a decrease in crop yields by up to 30%, thereby posing a very high risk to food security. Figure 5.3 shows the uneven trends in rice exports which strongly explains the variability in the production of rice. Therefore, there is a strong need for an in-season assessment of the rice-crop area and yields for the formulation and implementation of policy-related rice exports and food security management.

Numerous works have been carried out for rice-area estimation, using both RS as well as the conventional field-based sampling approaches. The Bangladesh bureau of statistics (BBS) is the agency that is in charge of rice-area mapping. It utilizes conventional methods such as crop-cut surveys and statistical approaches ("Yearbook of Agricultural Statistics-2017" 2018). This approach is cumbersome and inefficient as it requires manual field data collection, rich sampling, and significant post processing before releasing any reliable statistics on crop area. But that

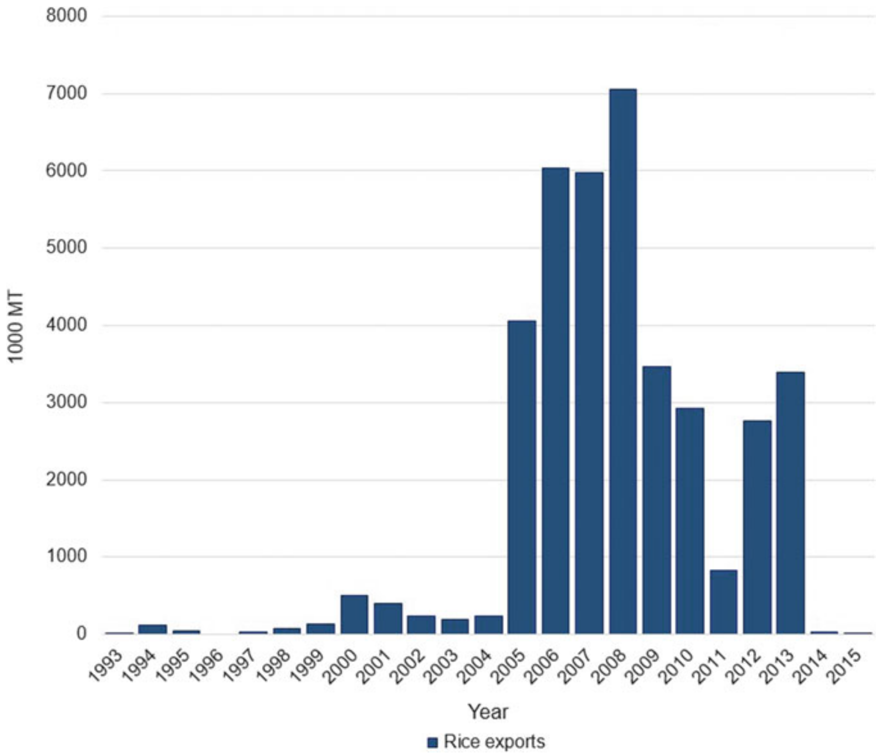

Fig. 5.3 Rice export of Bangladesh. Source: BARC

is slowly changing—in recent times, the BSS, in collaboration with various research institutes and NGOs, has been working on rice-area estimation using RS techniques which have several advantages over the conventional approaches.

In the meantime, researchers have been using both optical and SAR data with spatial extents for crop mapping (mainly rice). Some of their approaches have been: unsupervised and supervised (Cheema and Bastiaanssen 2010; Konishi et al. 2007; Lin 2012; Turner and Congalton 1998), rule-based (Boschetti et al. 2017), phenology-based (Dong et al. 2015, 2016), and time-series classification algorithms (Dong et al. 2016; Shew and Ghosh 2019). Besides, MODIS too has been effectively used for rice mapping and monitoring application scales (Burchfield et al. 2016; Nelson et al. 2014; Shapla et al. 2015). This is mainly due to high repetitiveness, the relatively small data size, and the high spectral resolution, and available bands which are particularly pertinent to agriculture (Whitcraft et al. 2015; Zhang et al. 2017). Further, MODIS time-series images have been integrated with data from the ENVISAT in rice mapping (Nelson et al. 2014). However, due to its coarser resolution (250 m), using MODIS for crop-type mapping has its limitations in Bangladesh due to small field sizes.

Bangladesh's SPARRSO has also attempted to use RS for rice monitoring using MODIS data and the AI-based semi-automatic approach (Shew and Ghosh 2019; Rahman and Hossain 2014; Begum and Nessa 2013). Besides, the time-series seasonal maximum value NDVI composites from MODIS data were used for classifying the rice fields in Bangladesh (Gumma 2011). In 2014, Nelson et al. attempted to integrate SAR and optical data for rice-crop mapping. They used MODIS and ENVISAT, as also phenology, to map the rice fields in Bangladesh. However, they have not yet reported on the achieved accuracy. Earlier, in 2013, multi-date SPOT images and ISODATA image-classification techniques had been used for rice mapping (More and Manjunath (2013)). Change detection techniques too have been used in Bangladesh—to assess the surplus or deficiency in rice cultivation—based on a phenological analysis of MODIS data (More and Manjunath 2013; Shapla et al. 2015).

Some of the studies have also taken advantage of the high-resolution SAR and optical data, along with cloud-computing techniques like GEE, for mapping different crops. Recently, Singha et al. (2019) used the high-resolution SAR Sentinel-1 and MODIS data on the GEE platform for mapping rice in Bangladesh, and they reported more than 90% accuracy. Similarly, Shew and Ghosh (2019) utilized EVI and the normalized difference fraction index (NDFI) derived from the landsat archive on the GEE platform for mapping rice in the country. These approaches focus more on commission error—i.e., if a pixel in an image is classified as rice, but it is not—and less on omission error, i.e., if a pixel in an image is non-rice, but is classified as rice.

5.1.5 Global RS-Based Crop-Mapping Techniques

Globally, several researchers have developed methods for crop-type mapping using different RS techniques. These techniques can be classified as those based on: sensors—optical or SAR (Inglada et al. 2015), the resolution of satellite data (Wardlow and Egbert 2010), and threshold and classification.

The remote sensing data sets, both optical and SAR, utilized time-series NDVI profiles for identification of seasonal thresholds, which is utilized for classifying different crop types. The acquisition time of the image plays a major role in identification and classification of different crop types. The information on life cycle, i.e., sowing, growing, and harvesting time of any crop is obtained by consulting the crop calendar. Although time-series NDVI thresholding approaches require fewer number of samples from the ground, they enable high accuracy even though they are unable to classify crops with similar phenological characteristics (with the same sowing, peak, and harvest time).

Alternatively, machine-learning classification algorithms, such as random forest (RF), support vector machine (SVM), and artificial neural network (ANN) require a systematic sampling approach and an ample amount of accurate ground samples for training the classification model (Tatsumi et al. 2015; Camps-Valls et al. 2003;

Murmu and Biswas 2015; Tamiminia et al. 2015; Gao et al. 2018; Sonobe et al. 2014). Here, it has to be noted that poorly sampled and inaccurate sample data from the field results in under fitting and overfitting of the classification model and therefore may result in overestimation or underestimation of the classification results (Liakos et al. 2018). The study of Tiwari et al. (2020) provides detailed insights into well-known crop-type mapping methods using different sensors and resolutions.

5.1.6 Challenges and Needs

Despite several approaches available for crop-type mapping, developing a systematic framework for crop-area assessment in the two countries is rather challenging. The key challenges are field inaccessibility because of tough topography, security concerns, the phenomena of cloud cover which restricts the use of optical imagery, low Internet bandwidth to download the satellite data, and limited computing infrastructure for data processing and analysis. The challenges in both the countries are depicted in Table 5.1.

The system was developed harnessing the power of multisensory remote sensing (RS) imagery (optical and SAR) and cloud-computing (GEE) techniques (Gorelick et al. 2017; Dong et al. 2016). The system has been designed keeping in mind the challenges in the region and provides the capacity for operationalization. It can provide independent and evidence-based information on the status of annual crops at the province level. And by ingesting field data at regular intervals for different seasons, the system would achieve higher accuracy in crop area estimates at the subnational level too.

Table 5.1 Challenges for Afghanistan and Bangladesh in crop mapping

Country	Internet bandwidth	Computing infrastructure	Field accessibility	Security concerns	Cloud cover
Afghanistan	Limited, high-speed Internet only available in the cities	Limited	Limited field accessibility because of the topography	Not safe to carry out fieldwork	Availability of optical data is limited during the wheat-growing period due to heavy cloud cover in the winter season
Bangladesh	Limited, not available everywhere in the country, especially in remote villages	Limited	Limited field accessibility, especially during monsoon because of floods	No safety issues	Availability of optical data is limited during the summer-rice and Boro-rice harvest seasons due to cloud cover in the monsoon season

5.2 Setting up Crop Interpretation Applications and Operation

The workflow for in-season crop mapping that is being implemented by SERVIR is shown in Fig. 5.4. Broadly, the methodology has six major components. The first step is reference data preparation. This involves the collection of ground sample points and quality check, after which the reference data is prepared for training and validation. In the second step, the agriculture mask (representation of agriculture area) is delineated which is used in the further stages. After obtaining the

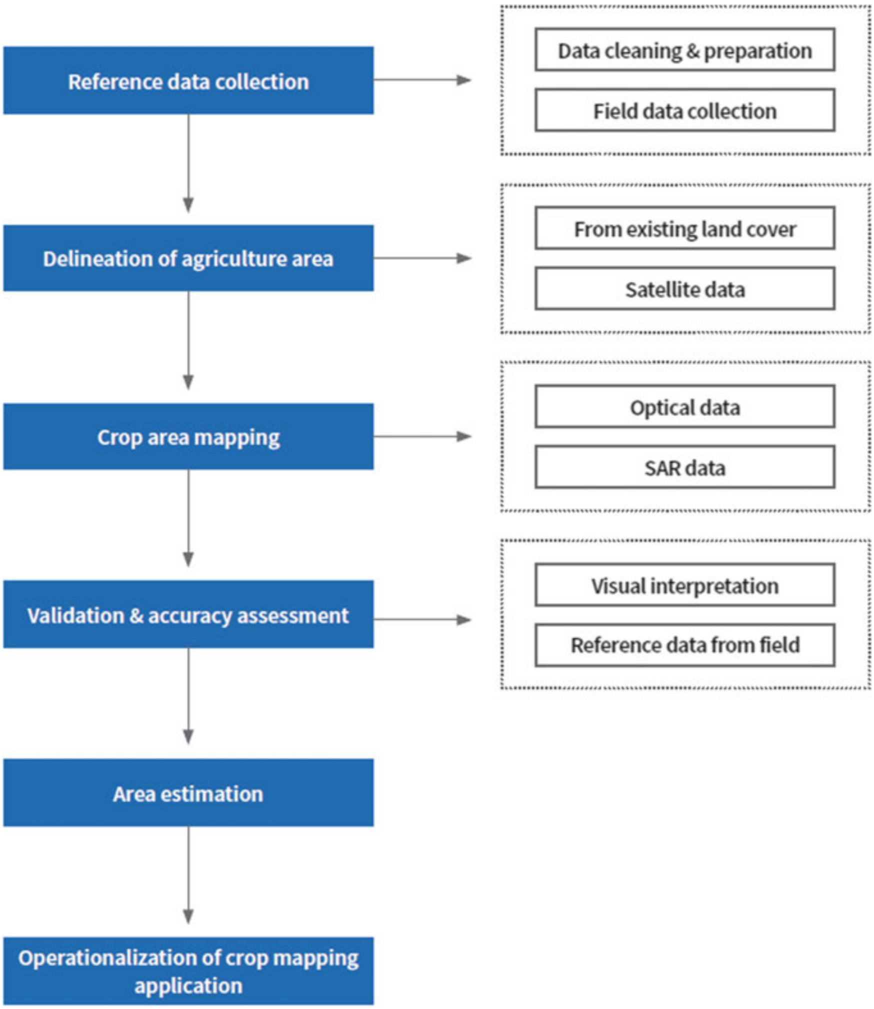

Fig. 5.4 Methodology of crop mapping

agriculture mask, the crop mapping is done in the third step using optical and SAR data to obtain a crop map. This crop map is then validated at the fourth stage using validation samples. In the fifth step, the crop area is calculated using the resolution of the images and pixel counts. In the final step, the application is customized for operationalization and to disseminate the results.

Each of these components is described in detail from Sects. 5.2.1–5.2.3.

5.2.1 Reference Data Preparation

5.2.1.1 Field Data Collection

Crop mapping based on RS techniques requires reference data from the ground. The reference data preparation is a process of collecting data from the different sources described in Fig. 5.5. The collected reference data from the various sources are then utilized for training and validation of the crop classification model. These data sets are broadly categorized as qualitative (based on social surveys and field forms) and quantitative data (based on GPS location and the geo-tagged photographs of crops). Qualitative data provide information on the crop cycle, crop rotation, crop conditions, production, and on the irrigation network. This information is utilized in developing crop calendars or for refining the existing crop calendars, and for deciding about the period of the satellite images which should be used for the crop assessment.

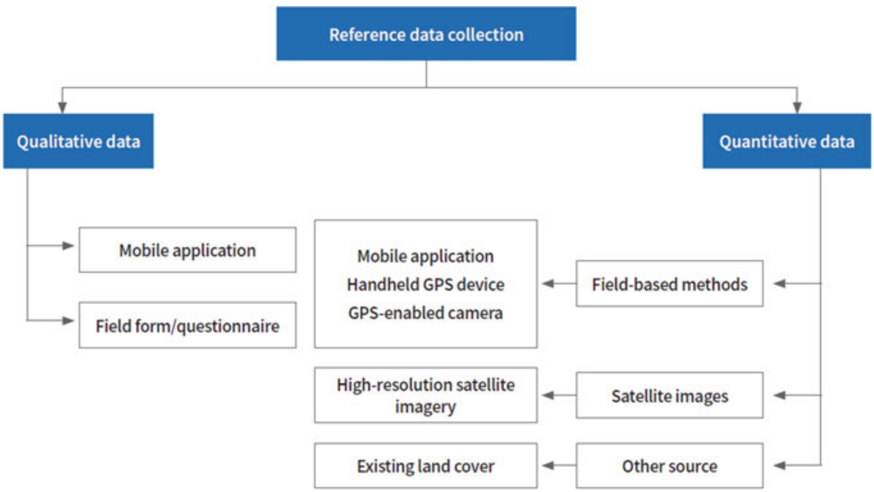

Fig. 5.5 Data collection workflow

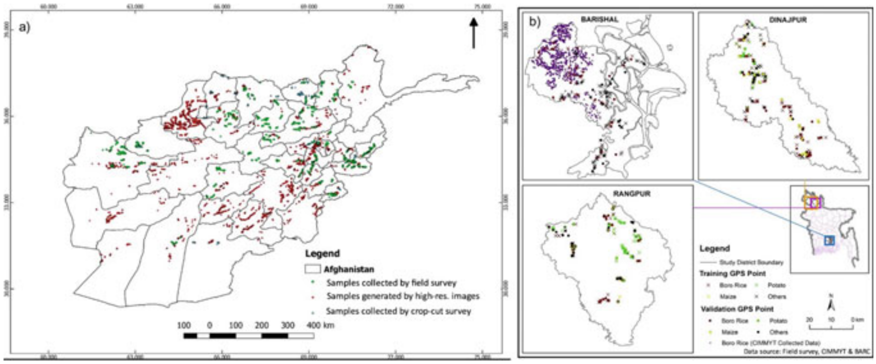

Fig. 5.6 Field data collection—**a** Afghanistan. **b** Bangladesh

In quantitative data collection, the GPS locations and multidirectional photographs of the crops are captured which are then utilized in understanding the crop dynamics and in training and validating the classification model for crop mapping. Depending on the type of the data, these data sets are collected using the different data collection platforms described in Fig. 5.5, such as mobile applications, handheld GPS, GPS-enabled camera, high-resolution satellite images, and existing land-cover maps.

Figure 5.6a,b shows the reference data collected from different sources in Afghanistan and Bangladesh using a random sampling approach. In Afghanistan, the quantitative reference data were collected using a field-based method (GPS-enabled camera), high-resolution satellite images (Pleiades and Google Earth images), and the existing food and agriculture organization (FAO) land-cover data (FAO 2010). The qualitative data were collected using field forms/questionnaires prepared by professionals from MAIL. In Bangladesh, both quantitative and quantitative reference data were collected using a mobile application (Geo-ODK) by professionals from the International Maize and Wheat Improvement Center (CIMMYT), BARC, and ICIMOD.

5.2.1.2 Data Cleaning and Preparation

The collected field data were then subjected to a quality check. This was because some of the samples were not taken from the middle of the crop field due to inaccessibility. So, the reference points collected from the corner of the crop field were then adjusted and moved inside the fields to make them useful for the training and validation of the models. The judgment was made on three criteria: the direction and orientation of the field photographs, the phenological characteristics of the crop, and the visual interpretations through high-resolution Google Earth images. The cleaned reference points were then merged and divided randomly into two categories—for training and validation; while 70% of the samples were used for training, the remaining 30% were utilized in the validation process.

5.2.2 Delineation of Agriculture Mask

For crop-area mapping, the delineation of agriculture areas is important, so as to confine the identification of specific crops within an agriculture mask. There are two ways of delineating an agriculture mask: by the existing land cover and by deriving it using optical time-series images. In the case of Afghanistan, the agriculture area was delineated using the existing FAO land-cover data (FAO 2010) and by extracting the area of agricultural land from it. Whereas, in the case of Bangladesh, the agricultural land extent was delineated by performing the random forest (RF) classification using ground reference points on time-series NDVI images derived from optical (Sentinel-2) images (from January 2017 to December 2018). The agriculture mask was delineated for two years (2017 and 2018) and combined to obtain the maximum agriculture mask.

5.2.3 Crop-Area Mapping

In RS-based crop mapping, two things are important and must be considered before proceeding to mapping: knowledge of the crop-growing season and selection of the data set (optical or SAR). The knowledge of the growing season of the target crop helps in deciding the time period for acquisition of satellite data which eventually helps in reconstructing the crop phenology through time-series NDVI (refer to Sect. 1.2). Phenology is measured commonly by the onset of greening, peak development during the growing period, the onset of senescence, and the length of the growing season (Hudson and Keatley 2010). The selection of the data set completely relies on cloud cover. Sometimes, despite using high-temporal optical satellite data sets (e.g., Sentinel-2), the crops cannot be separated using the optical data sets. This is because the intermixing/overlapping of NDVI (crop phenology) values with the limited cloud-free images makes it difficult to select the appropriate seasonal thresholds (sowing, peak, harvest).

Alternatively, SAR sensors have the unique capability to penetrate clouds and collect during all weather and are also sensitive to plant structure. However, SAR-based classification alone would require much more sample data on all the crops. Also, SAR is incapable of capturing the chlorophyll content present in the crops which is directly proportional to the growing stage of the crops. Therefore, SAR cannot alone be used for crop identification in case of limited availability of sample points. However, a crop map (developed from optical data) can be refined using SAR data under the following conditions:

- SAR data should have consistent time series in terms of incidence angle and should have a wide swath in mapping different crops (Inglada et al. 2016)
- The data should be preprocessed which entail: orbital file correction; thermal noise removal; terrain correction; and removal of speckle noise

5.2.3.1 Wheat-Area Mapping in Afghanistan

Wheat mapping (both for irrigated and rainfed crops) in Afghanistan was carried out at the district/provincial level in order to capture the phenological response of the crop. For this, time-series Sentinel-1&2 images were used. The mapping was done in two steps. At first, NDVI thresholds were determined by analyzing the field data for each province to separate the wheat area from other crops using Sentinel-2 (optical) imagery. Once the wheat areas were separated, Sentinel-1 (SAR) imagery was used to refine the estimated wheat area through an RF classifier. Then, after consulting a crop calendar, the time-series Sentinel-2A Level 1-C (top-of-atmosphere) satellite images with less than 30% cloud cover (from November 2016 to July 2017) were fetched. These images were preprocessed and masked with the agriculture mask (Sect. 5.2.2). Due to the cloud cover during the wheat-growing cycle, the seasonal NDVI median composites were generated for the sowing, peak, and harvest seasons of the wheat crop. Figure 5.7a,b shows the growth pattern of wheat and other crops for the Laghman and Helmand provinces of Afghanistan. After examining the growth pattern of different crops, it was found that the spatio-temporal (time-series NDVI) signal and growth pattern of vineyards are completely different from the wheat crop cycle. The NDVI values of orchards were found to be higher when compared to wheat in peak and harvest times. The NDVI response from vegetables varied a lot, but the values were generally lower than those of wheat during the peak and harvest seasons. A high degree of overlap between the NDVI values of opium poppy and wheat was also observed during the sowing period. As opium poppy has a shorter cropping season, a separation of the

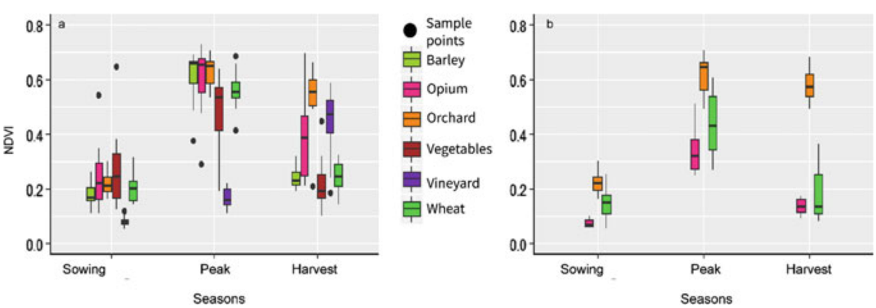

Fig. 5.7 Phonological characteristics of crops in the provinces of **a** Laghman. **b** Helmand in Afghanistan

former with barley would have been possible if cloud-free monthly images could have been obtained. Figure 5.7b shows the NDVI characteristics of opium poppy in Helmand which shows higher separability from wheat during the sowing and peak seasons.

The rule for defining the threshold for separating wheat from other crops is given in Eqs. 5.1–5.3.

$$\text{Minimum of NDVI}_{\text{wheat samples}} < \text{Wheat}_{\text{sowing}} \leq \text{Maximum of NDVI}_{\text{wheat samples}} \tag{5.1}$$

$$\text{Wheat}_{\text{peak}} \geq (\text{Minimum of NDVI}_{\text{wheat samples}}) \tag{5.2}$$

$$\text{Minimum of NDVI}_{\text{wheat samples}} < \text{Wheat}_{\text{harvest}} \leq \text{Maximum of NDVI}_{\text{wheat samples}} \tag{5.3}$$

In general, the NDVI seasonal composites were useful to distinguish wheat from orchards, vineyards, and some vegetables. It was also observed that much more separation between these crops could be achieved when combining data sets from the sowing, peak, and harvest times rather than using the sowing or peak times alone. However, a significant overlap in NDVI was still observed between wheat, opium poppy, and barley while using the optical image composites.

Therefore, in the second step, these crops (opium poppy and barley) were separated from wheat using Sentinel-1 (SAR) time-series data. These time-series Sentinel-1 data sets had been preprocessed by orbital file correction, thermal, and speckle noise removal, as well as terrain correction. Monthly median composites were also developed for the entire wheat-crop cycle (i.e., from sowing till harvesting). After performing analysis on Sentinel-1 SAR data, it was observed that different crops had different and unique response patterns across the different growth phases of wheat. However, the variability of responses showed overlaps and made it difficult for threshold-based separation (Fig. 5.8a,b). Therefore, an RF classification technique was performed on time-series Sentinel-1 data using training

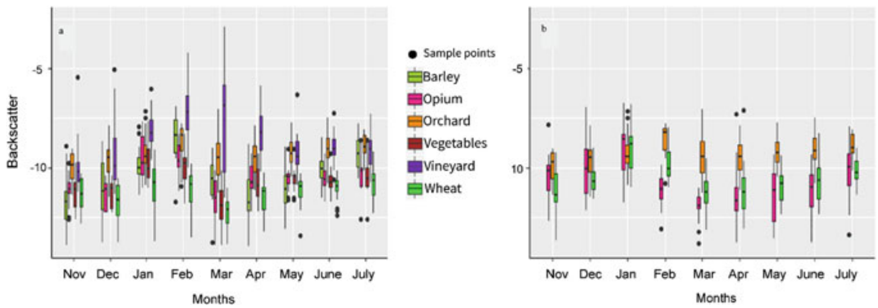

Fig. 5.8 Phenological characteristics observed using Sentinel-1 SAR data in **a** Laghman. **b** Helmand provinces in Afghanistan

sample points to separate the wheat from the other crops. The RF classification was applied within the classified mask generated from the optical image analysis. This step was applied only after the harvest season.

5.2.3.2 Boro-Rice Mapping in Bangladesh

Bangladesh has a different crop calendar for Boro rice (Islam and Hossain 2012) since it demonstrates wide variability in its growing seasons across the entire landscape. Therefore, the mapping of Boro rice was done at the district level to capture the unique phenological responses, region-wise. Time-series Sentinel-1 and -2 (optical and SAR) images were used for mapping Boro rice in three districts—Rangpur, Dinajpur, and Barisal. Because of the availability of an adequate number of randomly collected samples from the field, time-series Sentinel-1 images were utilized in the first step followed by time-series Sentinel-2 data in the second step for refinement of the Boro-rice map. Firstly, the time-series Sentinel-1 images from November 2018 to May 2019 were collected. After that, the images were masked using a delineated agriculture mask (Sect. 5.2.2). Sentinel-1 has two bands (VV and VH); therefore, to test the most suitable band for Boro-rice mapping, Sentinel-1 images were classified using training samples from different crops. Three combinations were tested (VV, VH, and VV + VH) for the classification using RF classifiers for mapping Boro rice and other crops. The highest accuracy was observed while using cross-polarization data sets (VH)—an accuracy of 92.10%; this was followed by VV + VH (86.48%) and VV (71.05%). The backscattered response from VH band was also examined (Fig. 5.9a). Different backscattered patterns were observed for different crops because of the sensitivity of the backscatter toward the crop structure. Since the highest accuracy was achieved using VH, the classification was performed using Sentinel-1 (VH) band to classify Boro rice and other crops.

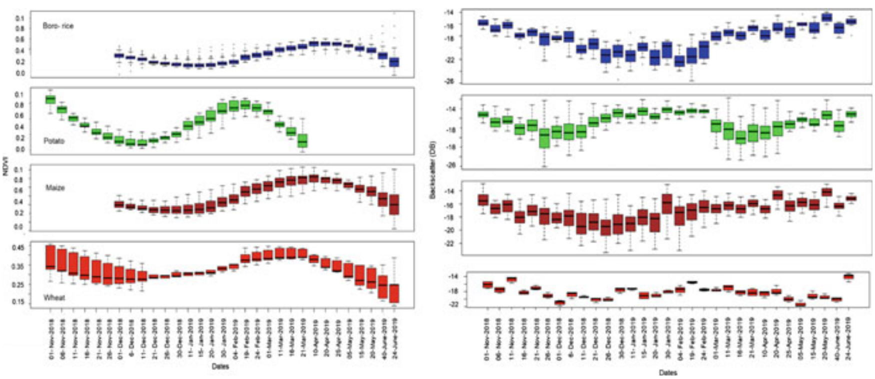

Fig. 5.9 Phenological characteristic of crops determined by using **a** Sentinel-2 (Optical) data. **b** Sentinel-1 (SAR) data

In step two, the Sentinel-2 (optical) data were used to refine the results obtained in step one. Figure 5.9b shows phenological characteristics of different crops, i.e., Boro rice, maize, wheat, and potato using Sentinel-2 data. By examining the phenological characteristics of these major crops, it can be interpreted that potato's sowing, peak, and harvest seasons differ completely from other crops, while Boro rice, wheat, and maize have different length of the season and slightly different sowing and harvest times. Also, the cropping cycle of these crops (maize, Boro rice, and wheat) can vary because of late sowing or early harvest and sowing. The classification results obtained using Sentinel-1 data may have high accuracy, but it may have overestimation in terms of area. This is mainly because of the dependence of the RF classifier on an ideal number of ground sample points (of different crops) for training. This might result in overfitting or underfitting of the classifier and ambiguity in the estimated area. Therefore, to further refine the results, Sentinel-2 time-series images were utilized using the phenological and threshold-based approach discussed in Sect. 5.2.3.1. Sentinel-2 images with less than 20% cloud cover (from November 2018 to June 2019) were utilized. The NDVI thresholds were derived using Eqs. 5.1–5.3 and were applied on the Boro-rice map derived from the Sentinel-1 images for further refinement of the result.

5.3 Validation and Area Assessment

The validation and area assessment of the maps were done using the standard RS-based accuracy assessment technique. The accuracy assessment was conducted in three ways: the results were checked by comparing with various ancillary data to identify gross errors, by visual interpretation, and by quantitative accuracy assessment. A confusion matrix/error matrix was also generated, and statistical accuracy assessment primitives such as the producer's and user's accuracy, including the Kappa coefficient, were utilized in understanding the distribution of errors. The confusion matrix for Afghanistan and Bangladesh for wheat and Boro rice, respectively, is depicted in Tables 5.2 and 5.3.

In RS-based classification, the area for the class can be calculated by counting the number of pixels in a particular class and resolution of the classified map. Equation 5.4 (below) is generally used for estimating the crop area.

$$\textbf{Crop area}\,(\textbf{ha}) = \frac{(\text{Pixel count}) * (\text{resolution of the image}) * (\text{resolution of the image})}{10,000} \tag{5.4}$$

Figure 5.10a,b shows the distribution of wheat (in Afghanistan) and Boro rice (in Bangladesh), whereas Fig. 5.10c,d depicts the areas of wheat and rice, respectively.

Table 5.2 Accuracy assessment of Afghanistan

Class	Non-wheat	Irrigated wheat	Total	User's accuracy (%)
Irrigated wheat				
Non-wheat	1839	282	2121	86
Irrigated wheat	341	1388	1729	80
Total	2180	1670	3850	
Producer's accuracy (%)	84	83		
	Overall	83.8 (%)		
	AC	0.50		
	Kappa	0.67		
Rainfed wheat				
Non-wheat	710	59	769	92
Rainfed wheat	58	238	296	80
Total	768	297	1065	
Producer's accuracy (%)	92	80		
	Overall accuracy	89 (%)		
	AC	0.59		
	Kappa	0.77		

Table 5.3 Accuracy assessment for Bangladesh

Class	Boro rice	Other crops	Total	User's accuracy (%)
Boro Rice	609	18	627	97
Other crops	3	95	98	97
Total	612	113	725	
Producer's accuracy (%)	99	84		
	Overall	97 (%)		
	AC	0.75		
	K	0.88		

5.4 Service Delivery

5.4.1 Operationalization/Application Development

The dissemination of the final results for Afghanistan was done through the development of a web-based visualization system as depicted in Fig. 5.12. Such a web-based visualization system is also planned for Bangladesh. The Afghanistan portal can be accessed via the following URL: http://geoapps.icimod.org/afwheat/. The wheat and Boro-rice mapping workflow was implemented in GEE using a customized interface. The modules (https://code.earthengine.google.com/?accept_

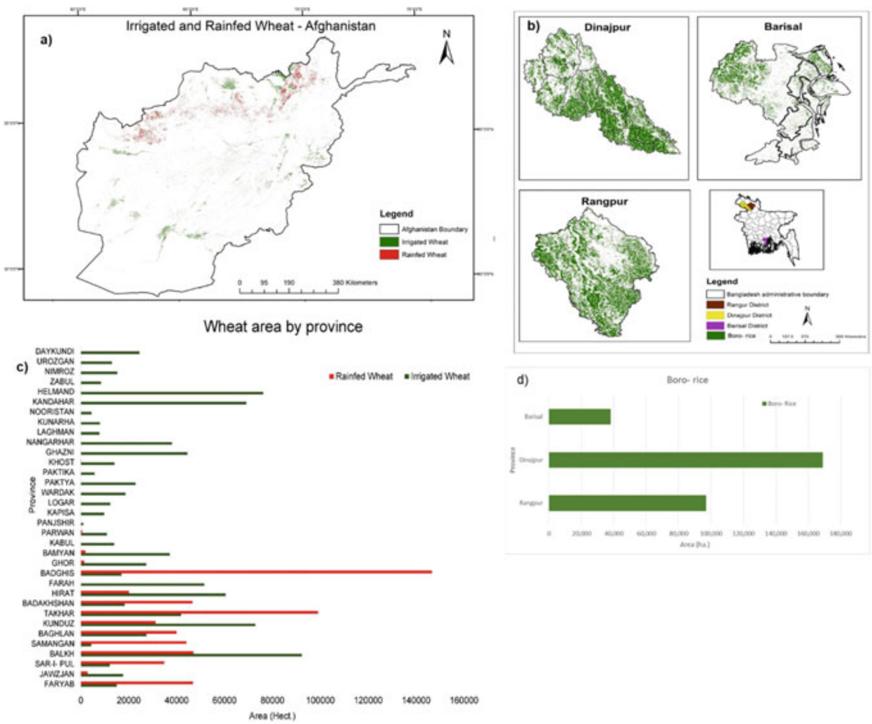

Fig. 5.10 **a** Distribution of wheat in Afghanistan. **b** Distribution of Boro rice in selected districts of Bangladesh. **c** Wheat area in Afghanistan. **d** Boro-rice area in selected districts of Bangladesh

repo=users/varunkt91/Wheatmapping) depicted in Fig. 5.11 shows how crop mapping is performed. A total of four modules were developed for: phenological profile assessment, reference data preparation, crop mapping using optical data, and for crop mapping using SAR data.

5.4.2 *Technology Transfer (Capacity Building)*

Capacity building is a key element in the sustainability of any project. The details on the framework of capacity building are described in Chap. 14. A number of training events (on-the-job training) were organized in crop mapping for building the capacity of the relevant professionals from MAIL and BARC. On-the-job training focused on agriculture mapping using optical and SAR data, and on wheat and rice mapping using GEE-based applications (described in Sect. 4.1). In addition, training on RS and GIS, a basic introduction on GEE, and field data collection application Geo-ODK were also organized. The OJTs were conducted mainly in Kathmandu, Kabul, and Dhaka.

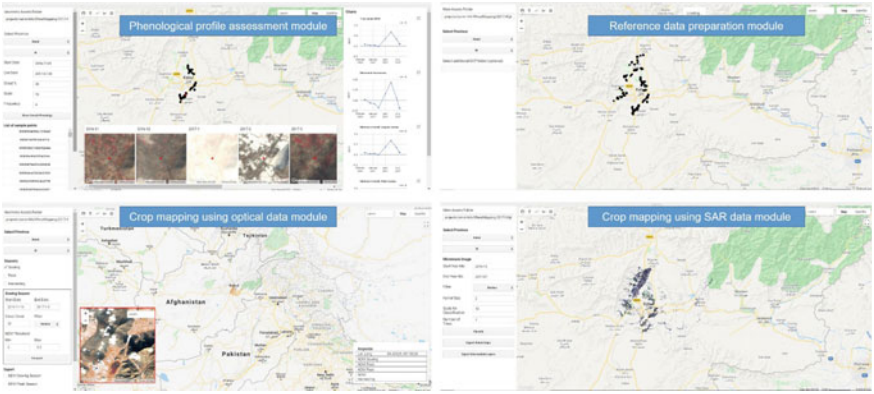

Fig. 5.11 Customized GEE-based application for crop-area mapping

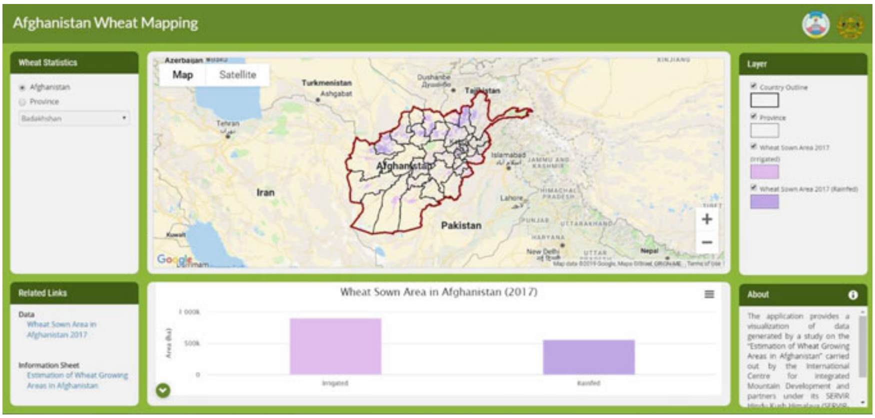

Fig. 5.12 A web-based visualization system for wheat in Afghanistan

5.5 Conclusions and Way Forward

In this chapter, a systematic and robust framework for mapping wheat (in Afghanistan) and Boro rice (in Bangladesh) has been explained. This framework has good potential for operationalization to strengthen the food security management of both the countries. The overall framework was designed keeping in mind challenges such as limited Internet bandwidth, scarcity of ground samples, and cloud-free optical images.

The system uses a multistep approach to provide area estimation as the wheat and Boro-rice season progresses in Afghanistan and Bangladesh, respectively. However, the methodology can also be utilized to map other varieties of rice such as Aman (spring rice) in Bangladesh if sample points are available for the spring season. In the first stage, time-series Sentinel-2 was used to map different crops using a phenology-based approach in different seasons. While in the second stage, time-series Sentinel-1 (SAR) data sets, along with the RF machine-learning classification technique, were utilized to refine the result. The first estimation was provided during the peak season to give an early indication about the cultivated areas of wheat and Boro rice. A more accurate estimation was provided immediately after the harvest season. The entire workflow was automated in GEE considering the low capacity and the need for timely estimation of the crop area. Meanwhile, capacity building activities—mainly in the area of crop mapping and monitoring using GEE—in order to enhance the skills of the local staff in government agencies are under way through the SERVIR initiative.

These two case studies from Afghanistan and Bangladesh are primarily about RS-based crop-area assessment. A standard RS-based method was utilized for accuracy assessment which provided statistical exactitude based on the Kappa coefficient and primitives such as user and producer accuracy (Sect. 5.3). However, in remote sensing-based crop-area estimates can be adjusted by performing bias adjustment using ground-based area measurement. This can only be achieved by incorporating more robustly sampled ground truth data for different crop samples. Such a bias-adjusted area provides for a more robust insight into the mapped area of any class of crop. The logistics and feasibility of acquisition of adequate sample data required for this method have to be ensured before deciding the use of such method.

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Chapter 6
Regional Land Cover Monitoring System for Hindu Kush Himalaya

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6.1 Introduction

The land cover across the HKH region is changing at an accelerated rate due to the rapid economic growth and population pressures that are impacting the long-term sustainability of ecosystems (Fig. 6.1) and their services, including food, water, and energy (Neupane et al. 2013; Wester et al. 2019; Rasul 2016; Song et al. 2018). The vast changes happening in the forested and vegetative areas are leading to changes in environmental and climatic conditions (Hansen et al. 2001). These land cover classes are critical for maintaining the Earth's surface energy balance between the atmosphere, pedosphere, and soil (Duveiller et al. 2018; Schäfer and Dirk 2011).

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https://doi.org/10.1007/978-3-030-73569-2_6

Fig. 6.1 Rapid conversion of agriculture land into built-up areas in Kathmandu valley. Photo by Jitendra Raj Bajracharya

Therefore, the accelerated changes in land cover have the potential of causing long-term impacts on many sectors in the HKH region (Xu et al. 2008, 2009).

Land cover mapping is one of the most common applications of EO, which renders meaningful information about the Earth's surface. Changes in land cover are occurring due to both natural and anthropogenic drivers and range from local to global scales. Using a land cover map, policymakers can have a better understanding of a vast landscape and the changes that are taking place in it. To estimate the historical changes over time, past land cover data for different years is critical. This change data provides vital information to land managers so that they can monitor the potential consequences of the ongoing interventions and make decisions that are right in terms of future management. The mapping of land cover and land cover change also helps to get insights into the complex interactions between human activities and global change (Running 2008; Giri 2005; Keenan et al. 2015; Uddin et al. 2015a). Global coverage at regular intervals and a wide range of spatial resolutions offered by EO satellites make them the best source of information for mapping land cover and understanding its dynamics (MacDicken et al. 2016; Estoque 2020; Giri 2012). Land cover data products are also used as a key input for various models of biodiversity, ecology, hydrology, disaster impact, food security, atmosphere, and many more (Chettri et al. 2013; Le Maitre et al. 2014; Karki et al. 2018; Ahmed et al. 2018; Carlson and Arthur 2000; Giri 2012; Uddin et al. 2020). There have been several projects related to land cover classification and change detection in the HKH region conducted by various organizations (Table 6.1) using medium resolution satellite images. However, a project-based land cover mapping does not always meet the requirements beyond the specific users involved in the mapping. Various agencies and institutions often do not share the necessary reference data which is crucial for systematic land cover mapping efforts. For decision-making purposes, the national agencies (usually the national forest departments) are mostly using single-year, often backdated, national land cover maps with limited capability to monitor in a timely or integrated fashion (Vidal-Macua et al. 2017; Kaim et al. 2016). The land cover data produced through these projects does not always fully meet the requirements of activity data for national and international reporting on the estimation of forest carbon fluxes. As a result, global land cover products are frequently used as the best available alternative when appropriate and timely maps are not available at the regional, national, or subnational levels (Gong et al. 2013). These land cover products also have limitations given they have been created using different sensors and different techniques at varying spatial resolution and classification typologies resulting in inconsistencies on global scales (Verburg et al. 2011; Bajracharya et al. 2009). These inconsistencies often hinder the practical and multiple uses of land cover layers to contribute to planning and policy formulation, as well as overall management (Ziegler et al. 2012; Skole et al. 1997; Coulston et al. 2014).

Recognizing the land cover data gaps inconsistent land cover maps in the HKH countries, ICIMOD initiated the development of regional land cover maps using a harmonized classification schema by adopting the land cover classification system (LCCS) of the FAO. During the first phase of SERVIR-HKH initiative, it developed land cover maps of 1990, 2000, and 2010 based on Landsat images using the object-based image analysis method, for the entire countries of Nepal and Bhutan and the mountain areas of Pakistan, Bangladesh, and Myanmar (Gilani et al. 2015; Qamer et al. 2016; Uddin et al. 2018, 2015). These maps made it possible to analyze changes at a decadal scale since the data for all the three years was prepared using consistent sources, classification schemes, and methodologies. At the beginning of the second phase of SERVIR-HKH, the stakeholders prioritized the need for an annual land cover monitoring mechanism called the regional land cover monitoring system (RLCMS). This was in the wake of the fact that the preparation of land cover maps using object-based segmentation requires substantial time to generate land cover data for each year. The traditional supervised classification system using desktop software also requires large computing and data storage resources. The availability of human and financial resources within these national agencies was also a major obstacle in implementing such operations. The main objective of RLCMS was to develop a system to produce annual land cover maps for the entire HKH region using a robust method and a harmonized classification scheme that could be updated with less human and computing resources. The specific objective was to develop the methodology and workflow, produce annual land cover maps for the years 2000–2018, and develop the capacity of the regional stakeholders to apply the relevant techniques. Co-development, co-learning, and

Table 6.1 Land cover products in the HKH countries

Country	Satellite/sensor	Spatial resolution	Period of data acquisition	No. of classes	References
Afghanistan	SPOT 4, Landsat TM, Aerial photographs, IKONOS, QuickBird	20 m 30 m 1 m 1 m 0.6 m	2009–2011	11	(FAO 2012)
	Landsat TM	30 m	1990, 1993	11	(FAO 2001)
	Aerial photographs	–	1960–1970	10	(FAO 1999)
Bangladesh	Landsat TM	30 m	2005	14	(Altrell et al. 2007)
	Landsat MSS/ETM	30 m	1977, 2000		(Uddin and Guring 2010)
	NOAA AVHRR HRPT	1.1 km	1985–1986; 1992–1993	9	(Giri and Shrestha 1996)
	Landsat imagery	30 m	1981		(FAO 1981)
Bhutan	ALOS	10 m	2006–2009 winter season	11	(MoAF 2011)
	Landsat	30 m	1990, 2000, and 2010 (change detection)	10	(Gilani et al. 2015)
China	Landsat TM	30 m	1995–1996; (updated in 2000, 2005, 2008, and 2010)	25	(Liu and Tian 2010) (Chen et al. 2011)
India	Landsat MSS	80 m	1984–1985	14	(Roy et al. 2015)
	Landsat and IRS 1B	30 m and 72 m	1994–1995		
	Landsat and Resourcesat I	30 m and 23.5 m	2004–2005		
	AWiFS	56 m	2005–2006	18	(NRSA 2007)
	Resourcesat-2 LISS III	23.5 m	2011–2012		(NRSC 2012)
Myanmar	Landsat 8	30 m	October 2014–March 2015	11	(MONREC 2006)
Nepal	RapidEye MSS	5 m	February–April 2010/11	3	(DFRS 2015)
	Landsat TM	30 m	November 2010 – February 2011	12	(Uddin et al. 2015)
	Aerial photograph	–	1979	5	(LRMP 1986)
Pakistan	SPOT 5	2.5 m	2007–2008	19	(PFI 2012)

joint validation pathways were also planned to ensure the sustainability of the system. The generated land cover data was then disseminated through a customized application.

6.2 The Approach of RLCMS

As SERVIR HKH initiative transitioned to the second phase, land cover mapping was still one of the priorities. Specifically, the stakeholders, and they were interested in having updated maps at more frequent intervals than those of decades. It was the time when cloud computing was evolving as a strong platform for large-volume image analysis, and the University of Maryland (UMD) and the World Resources Institute (WRI) had set an example by implementing Global Forest Watch using GEE. Around the same time, the newly established SERVIR-Mekong, led by the Asian Disaster Preparedness Center, was conceptualizing and building the RLCMS for Lower Mekong region. The approach and methodology have been published in Saah et al. (2020), and Khanal et al. (2020). The RLCMS adopted a modular architecture built on the GEE computational platform which applied cloud computing and storage frameworks and thus enabled parallel calculations on a large series of data. This made it possible to generate land cover maps at national and regional scales more efficiently and at any desired temporal frequency. Realizing the changing paradigm in land cover mapping technologies and the benefits offered by GEE, SERVIR-HKH and SERVIR-Mekong joined hands to collaborate on expanding the RLCMS to the HKH region. To enable these systems the GEE outreach team provided cloud storage facilities and technical expertise. The basic structure of RLCMS was co-developed through a series of user engagements from 2016 to 2017 in the Mekong region which was later extended to the HKH region in 2018. The details of the RLCMS approach are outlined in Khanal et al. (2020); Saah et al. (2019), while the land cover methods are provided in Saah et al. (2020).

The key highlight of the RLCMS approach is co-development through partnerships and stakeholder engagements which ensure a sense of ownership and trust in developing land cover maps. The joint working environment has enabled a pathway for capacity development in terms of the sustainability of RLCMS (Saah et al. 2019). In the partnership configuration, SERVIR-Mekong and SERVIR-HKH are the regional hubs responsible for implementing the system with regional and country partners in the Lower Mekong and HKH regions, respectively. NASA, the United States Forest Service (USFS), the University of San Francisco (USF), and the GEE outreach team provided the technical assistance for developing the algorithms and implementing them in GEE. NASA also continues to collaborate with the FAO for development of an online reference data collection system called Collect Earth Online (CEO). Collaboration with FAO continues to implement the RLCMS framework in FAO SEPAL (System for Earth Observation Data Access, Processing and Analysis for Land Monitoring) in order to build a user-friendly interface for the RLCMS. This collaborative process has provided opportunities by leveraging the best practices and the most advanced state-of-the-art technologies on land cover mapping (Saah et al. 2019b). Besides, there were additional collaborations for specific needs, for example, the University of Maryland supported to customize a tree cover algorithm for producing data on tree cover and height.

To address the different needs of the various stakeholders, the RLCMS approach adopted five key principles: exercising flexibility to accommodate the requirements of land cover typologies; maintaining consistency across time and space; regarding remote sensing data as the source; understanding measurable uncertainty; and developing capacities (Saah et al. 2019).

A recent trend on image analysis shows that GEE is growing widely as an analysis platform because it provides publicly available multi-petabyte satellite imagery at planetary scales without any cost. It is also highly efficient in comparison to desktop, server-based image processing, and is capable of processing vast areas immediately (Saah et al. 2020; Duan et al. 2020; Mahdianpari et al. 2019; Uddin et al. 2020). Building upon GEE as its core, RLCMS incorporates the needs of each country and maintains consistency and transparency using contemporary, robust methods, and provides user-friendly analysis tools and products, besides helping build the capacity of the partners (Saah et al. 2019).

6.3 Methods of Land Cover Mapping

The overall methodology of the RLCMS and its eight stages, as outlined in Fig. 6.2, are: defining the land cover classification system and land cover typology; collecting land cover training samples; selection of Landsat imagery, image correction, and preparation of annual composites; selection of additional thematic data, and creation of image indices and covariates to make input layers for machine learning; utilization of supervised machine learning algorithms and creation of land cover primitives, and primitives evaluation and smoothing; evaluation of annual tree canopy and height; preparation of customized land cover maps by modifying the assemblage logic using a decision tree; and validation of the land cover maps and assessment of their accuracy. The steps are described in the following sections.

6.3.1 *Defining the RLCMS Classification Schemes and Primitives*

Defining an appropriate classification system is the first step in developing RLCMS, as a land cover map with a well-defined legend can provide useful information on the geographical status of a specific area. Classification systems can describe land

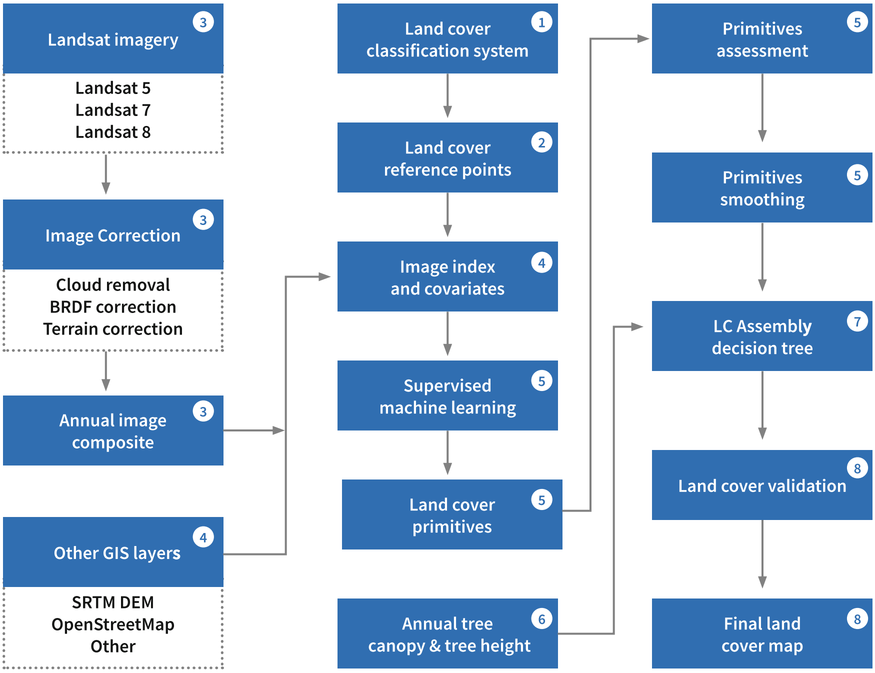

Fig. 6.2 Methodological framework for regional land cover mapping

cover features all over the world at any scale or level of detail. To identify land cover typology and to define the legend for RLCMS, the land cover classification system version 3 (LCCS 3), developed by the FAO (Di Gregorio 2016; Bajracharya et al. 2010; Gregorio 2005), was used. The LCCS provides a framework and assists users in systematically defining land cover categories through specific, observable land cover characteristics or attributes, along with the identification of their spatial and temporal relationships. The LCCS-based classification scheme utilizes the land cover element known as a primitive and employs biophysical entities that can be mapped and assembled into a final land cover map. Primitives are defined as the building blocks or the basis of a land cover class in the RLCMS approach (Saah et al. 2020). There can be one or more primitives for a particular land cover class. The definitions of land cover classes used for RLCMS with the corresponding primitives are given in Table 6.2, which are comparable for international reporting requirements for the countries and recommended by the IPCC (Penman et al. 2003).

For the development of this harmonized land cover classification system for the HKH region, different national and regional consultation workshops (Chap. 3) were conducted across the region involving professionals from key agencies. During the workshops, the stakeholders identified their needs as per land cover typology. At the regional scale, ten classes were defined (Table 6.2) to develop land cover maps for the whole of the HKH region. When the system was implemented at the national level to develop a National Land Cover Monitoring System (NLCMS), customized schemes were defined in consultation with the national stakeholders.

Table 6.2 Definitions of land cover classes

S/N	Land cover (LCSS)	Description	Comparability to IPCC class	RLCMS Primitives
1	Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under crop land or large settlement areas	Forest	Tree height, tree cover Tree
2	Grass land	This class describes the areas covered by herbaceous vegetation with a cover ranging from "closed to open" (15–100%). This category includes rangelands and pasturelands that are not considered as crop land	Grassland	Grassland
3	Crop land	This category includes arable and tillage land and agroforestry systems where vegetation falls below the thresholds for the forest land category, consistent with national definitions	Crop land	Crop land
4	Built-up	Built-up describes artificial structures such as towns, villages, industrial areas, airports, etc.	Settlements	Built-up, NDDBI
5	Water body	A river is a naturally flowing waterbody; typically, it is elongated and has a geomorphologic context. Lakes and ponds of perennial standing are also waterbodies	Wetlands	Open water
6	River bed	Riverbed is a tract of land without vegetation surrounded by the waters of an ocean, lake, or stream; it usually means any accretion in a river course		Riverbeds
7	Bare soil	A soil surface devoid of any plant material	Other	Bare soil
8	Bare rock	Non-vegetated areas with a rock surface		Bare rock
9	Snow	This class describes perennial snow (persistence >9 months per year)		Snow
10	Glacier	Perennial ice in movement		Glacier

6.3.2 Collection of Land Cover Training and Validation Data

The primary reference data was collected for each year from 2000–2020 using various sources. Field campaigns were conducted in collaboration with the national partners using a mobile app. Some data was collected from previous field campaigns by the partner agencies. Additional data was collected for national land cover mapping for each country. High-resolution satellite images were used to collect samples from earlier years using the Collect Earth Desktop or the CEO platform of the FAO. The CEO supports a systematic collection of reference samples using various high- and very high-resolution satellite images as background to meet the requirements of any land cover mapping project for different years (Saah et al. 2019a). The collected 51,002 systematic sampling reference data was divided into two subsets. Randomly, 85% were used for primitives development, while 15% were used for the accuracy assessment of the primitives and the final maps in order to produce a confusion/error matrix.

6.3.3 Satellite Image Processing and Land Cover Mapping

GEE has archived Landsat scenes that have undergone multiple procedures such as computation of the sensor radiance, top-of-atmosphere (TOA) reflectance, surface reflectance (SR), cloud score, and cloud-free composites (Sidhu et al. 2018). The yearly mapping of the HKH land cover from 2000 to 2018 was done using images from Landsat 5 with the Thematic Mapper (TM) sensor, Landsat 7 with the Enhanced Thematic Mapper (ETM+) sensor, and Landsat 8 with the Operational Land Imager (OLI) sensor.

However, a few more important image preprocessing steps still needed to be applied (Saah et al. 2020; Khanal et al. 2020) to these Landsat images to minimize solar illumination, atmospheric noise, and topographic effects. In brief, removing clouds from the images was an obligatory step in Landsat image processing. In this cloud-removal step, the pixel-QA band and a cloud-core algorithm that used the spectral and thermal properties of clouds were used to identify and remove those pixels with cloud cover from the imagery. Besides the cloud area, the cloud shadows were removed in order to avoid misclassification of the areas. For that, the Temporal Dark Outlier Mask (TDOM) algorithm was used (Housman et al. 2018). The pixel quality attributes generated from the CFMASK algorithm (pixel-qa band) were also used for shadow masking (Foga et al. 2017; Scaramuzza et al. 2011; Housman et al. 2018). During the image processing, the correction of the bidirectional reflectance distribution function (BRDF) was also applied following an algorithm developed by Roy et al. (2016). As most of the HKH region has a complex terrain, topographic correction was done to alleviate the illumination effects from the topographic position, aspect, and slope that divert reflectance values in the case of similar features within different territories (Carrasco et al. 2019; Riaño et al. 2003; Tokola et al. 2001). Once the process of image correction was completed, 80 covariates were generated based on the Landsat annual composites, and SRTM DEM was then used as input to supervise the classification. Thus, the image indices collectively provided a critical parameter for classifying land cover, and this has a noticeable correlation with the particular land cover association (Zhao et al. 2017; da Silva et al. 2019).

6.3.4 *Creating Image Indices and Covariates*

Image indices and covariates are synthetic image layers usually created by multispectral satellite imagery. These indices and covariates often provide a unique distinguished value on a particular land cover that is not found in any of the other individual band. Typically, a wide range of ecological information and plant characteristics is recognized through various indices as it increases the separability of the classes of interest by improving the spectral information. Usually, mapping in the HKH landscape is a challenging task because of topographic variations and heterogenic land cover patterns. The satellite image bands and indices usually emphasize a specific phenomenon that is present in particular land cover classes. Because of that, a set of image bands and covariance matrices is required for accurate classification. In order to effectively classify the land cover map for the HKH, typical Landsat bands—Band 1, Band 2, Band 3, Band 4, Band 5, Band 6, and Band 7—and the multiple indices were used. The indices and covariates were selected from a large number of image matrices through analysis of their importance. The indices used were: normalized difference vegetation index (NDVI); normalized difference moisture index (NDMI); soil adjusted vegetation index (SAVI); atmospherically resistant vegetation index (ARVI); enhanced vegetation index (EVI); green chlorophyll index (GCI); normalized difference water index (NDWI); and bare soil index (BSI) and the SRTM DEM-based slope, aspect were used as input in the regression tree for land cover primitives formation by machine learning. All of these indices and covariates, together with land cover training sets, generated a higher probability of classifying the primitives. The definition of the above indices and corresponding references is available at the index database website (Henrich et al. 2009; Henrich and Brüser 2012).

6.3.5 *Primitives Generation by Machine Learning*

A supervised machine learning random forest algorithm was applied to produce land cover primitives. For each primitive, the corresponding confidence (0–100) layer was generated. To reduce computational resources, the process of feature importance was performed to identify the covariates and indices with a stronger influence for each primitive. This gave a list of 15–30 bands for each classification that had the most impact on the results, which was then used as input for the classifier. Finally, generating land cover primitives, a random forest classifier was applied using the imported training sets, the Landsat image, and associated related raster layers.

6.3.6 Annual Tree Canopy Cover and Height

Tree and woody vegetation structure primitives include the annual tree canopy cover and canopy height maps. To improve regional consistency, the vegetation structure product was derived using the same approach as for the Lower Mekong region (Potapov et al. 2019). In order to map the woody vegetation structure, a set of LIDAR-based vegetation structure prediction models was applied regionally using the time series Landsat Analysis Ready Data (Potapov et al. 2019). Tree cover disturbances were detected separately and integrated into the structure's time series (Hansen et al. 2013).

6.3.7 Primitives Assemblage for Land Cover Mapping

Once the primitives were generated, a decision tree classifier was used to run through these primitives and hierarchically classify all the pixels into the final land cover classes (Fig. 6.3). After applying the decision tree, a minimum of 0.5 ha mapping units and continuous pixel counts were calculated for results throughout the study region which helped to remove any stray pixels or patches smaller than the minimum mapping unit. This whole process is referred to as primitive assemblage.

6.3.8 Validation and Accuracy Assessment

In order to ensure the reliability and credibility of the RS-based land cover map for the HKH, an accuracy assessment was considered as a mandatory step. In this regard, the most appropriate method is to validate the land cover map using the ground truth data which is considered to be a more authentic reference. Besides, the spatiotemporal consistency of the land cover data and similar types of products should be evaluated over national and regional representative locations and periods. However, as the HKH region consists of a vast area with rough topography and as there is a problem of inaccessibility, a field-based land cover validation approach was not possible. So, for validation of the land cover, we had to depend on CEO as it has a collection of very high-resolution images. As for the accuracy estimate, it is

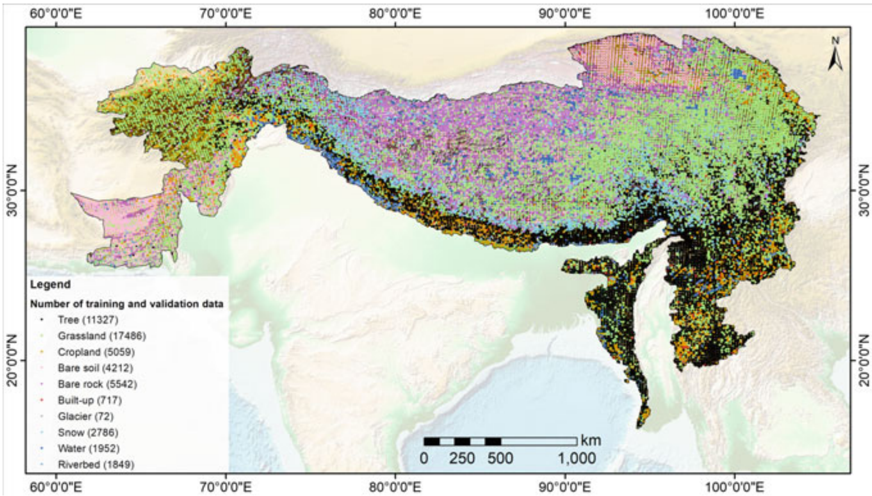

Fig. 6.3 Geographical distribution of reference data collection

derived from the error matrix generated from the validation data with their respective confidence intervals. The overall accuracy of 81.72% and the Kappa statistic values of 0.81 were achieved for the HKH land cover of 2018. These results show that the developed map datasets are reasonably accurate and agree well with high-resolution imagery (Table 6.3).

6.4 Results

The assembled land cover maps between 2000 and 2018 developed by RLCMS are presented in Fig. 6.4. Figure 6.5 shows the distribution of the area covered by different land covers. The results demonstrated that grassland was the most dominant land cover, followed by barren land which include areas with bare soil and bare rock. In the years 2000, 2005, 2010, and 2015, rangeland covered 37.2%, 37.6%, 38.7%, and 38.23%, respectively, of the total HKH region. During the same years, the second dominant land cover was barren areas which include bare soil and bare rock. In 2000, 2005, 2010, and 2015, bare soil and bare rock together covered 32.1, 31.37, 30.35, and 30.69%. The assessed crop land cover in 2000 was about 5.1% and about 5.41% in 2015. As for snow and glacier areas, they covered about 4% of the high-elevation section in 2018, while waterbodies and riverbeds together accounted for 2%. Figure 6.4 shows that topography plays an important role in natural vegetation and crop production. The weather and climatic situations also have some impact on the land cover patterns. In the HKH, forest cover is mostly

Table 6.3 Error matrix for the land cover map of 2018

Land cover	Waterbody	Glacier	Snow	Forest	Riverbed	Built-up	Crop land	Bare soil	Bare rock	Grassland	Total	User's accuracy (%)
Waterbody	36	0	0	0	0	0	6	0	0	1	43	83.72
Glacier	0	71	0	0	0	0	0	0	0	0	71	100.00
Snow	0	0	103	3	0	0	0	1	14	20	141	73.05
Forest	0	0	0	460	0	0	12	0	0	41	513	89.67
Riverbed	0	0	1	0	164	0	16	35	16	27	259	63.32
Built-up	0	0	0	0	0	66	11	1	0	3	81	81.48
Crop land	0	0	0	5	0	0	180	0	0	22	207	86.96
Bare soil	0	0	6	0	5	0	3	911	73	96	1094	83.27
Bare rock	0	0	25	0	0	0	1	72	659	114	871	75.66
Grassland	0	0	36	108	10	2	101	225	233	3366	4081	82.48
Total	36	71	171	576	179	68	330	1245	995	3690	7361	
Producer's Accuracy (%)	100.00	100.00	60.23	79.86	91.62	97.06	54.55	73.17	66.23	91.22		

Fig. 6.4 Land cover maps of the HKH region (2000–2018)

spread in the south and south-eastern areas, where precipitation is higher; the grasslands are mostly distributed in the north and north-western parts while agricultural land is mostly found in the southern part of the region.

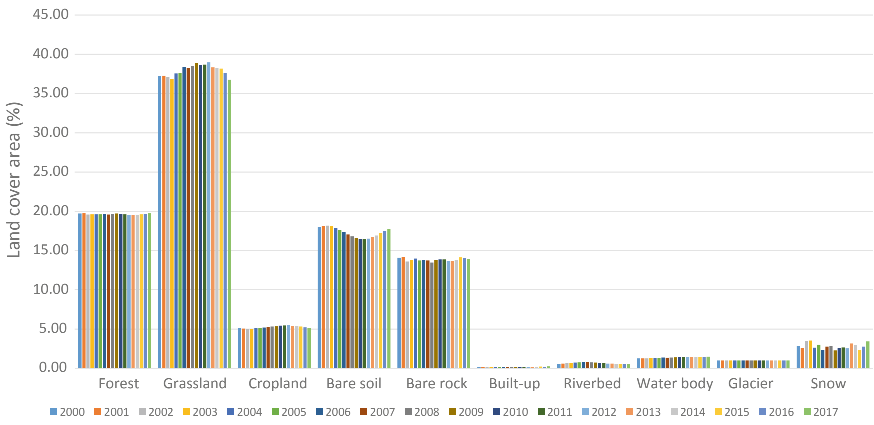

Fig. 6.5 Percentage of different land cover classes (2000–2018)

6.5 Implementation at the Regional and National Levels

The land cover mapping system was implemented at two levels. At the regional level, a spatially seamless and temporally consistent annual land cover maps of the whole HKH region were generated using the broad land use categories recommended by the IPCC; this is also suitable for regional-level change monitoring of carbon stock and GHG emissions (Penman et al. 2003; Li et al. 2017). However, in addition to the IPCC-specified classes, a few additional categories such as snow, bare soil, and bare rock which are important for the region have also been included.

At the national level, the system has been implemented to develop NLCMS in collaboration with the national agencies mandated for land cover mapping and monitoring. In Nepal, the system has been implemented in collaboration with the Forest Research and Training Center (FRTC). To implement RLCMS in Nepal, ICIMOD and FRTC partnered in developing the system. A technical team was formed, comprising of staff from FRTC and ICIMOD, and an advisory team too was set up consisting of senior management of FRTC and the senior leadership of SERVIR, to provide guidance. National workshops, supported by SERVIR and SilvaCarbon, were also organized with participants from most of the agencies using land cover data to get feedback on the classification scheme, data quality, and accuracy. FRTC and ICIMOD worked together for sample collection from images and fields, evaluating classification results and field validation.

In Afghanistan, a land cover map was produced by the FAO for 2010. The Ministry of Agriculture Irrigation and Livestock (MAIL) needed to update this map. Through a workshop attended by high-level officials from MAIL and other key government agencies, the RLCMS methodology and land cover legends for Afghanistan were finalized. A technical team consisting of staff from ICIMOD, MAIL, and the National Statistical Information Authority (NSIA) was formed to co-develop this map.

In Myanmar, NLCMS has been implemented jointly by SERVIR-Mekong, SERVIR-HKH, and the Forest Department. The land cover legends were defined in consultation with the latter.

In the case of Bangladesh, the Bangladesh Forest Department (BFD) carried out a mapping project to develop land cover maps for the years 2000, 2005, 2010, and 2015. The project was implemented by the FAO with funding from USAID. The land cover legend was defined using the FAO LCCS system through country consultations. The mapping was done by interpreting SPOT and Landsat images. Then, in order to update these maps, the BFD requested ICIMOD to implement RLCMS for mapping the 2019 land cover of Bangladesh. Toward this end, fieldwork and image-based sample collections were conducted jointly by a team consisting of members from the BFD and ICIMOD.

6.6 Challenges and Lessons Learnt

6.6.1 Class Definition

The accuracy of a land cover map depends highly on the clarity and unambiguity of the class definition. Before implementing the RLCMS method for generating land cover maps, priority was accorded to document the class definition so that all the users and developers could agree on it. However, there were some classes where the partners were unsure about how to define them. The following two examples elaborate it:

- A forest is defined as an entity with "more than 20% tree crown cover and average tree height more than 5 m within the minimum mapping unit" (Herold et al. 2009). However, when an area within a forest has very young trees with their height less than 5 meters, there arises a problem in defining that area. While some people argue that since these trees have the potential to grow beyond 5 meters, they should be grouped as a forest, but there are others who do not agree. One issue with RS technology is that it is not capable of determining future growth; it only classifies what is currently on the ground.
- Another confusion is about the classes of "other wooded land" and "open forest." In both cases, the canopy cover is between 20 and 50%.

6.6.2 Reference Data Collection

The accuracy of classification is also dependent on the number and quality of the reference data that are used. While in some cases, high-resolution images provide a good source of reference data, these images are not available for all the previous years. Besides, the accuracy of the reference data also varies with the operator collecting those data.

6.6.3 Comparison with Legacy Data and Statistics

The accuracy assessment of RS-based classification is usually done with statistically designed validation samples and by calculating various accuracy parameters. But in the HKH region, another issue interrupts the independent assessment of accuracy. Usually, the government agencies have the legacy data on land cover and the corresponding statistics, but they can be reluctant to accept any deviation from those earlier statistics.

6.6.4 Limitation of the GEE Cloud Platform

When processing the whole geographical region of the HKH, the image volumes were too large for a desktop computer to handle. Though GEE provides the opportunity to process these large areas, sometimes processing in GEE could not be done when the number of the reference sample were too many. In such cases, processing needs to be done in batches, focusing on a smaller area at a time. Typically, GEE allows a maximum of 100 million object features and 100,000 vertices for each row's geometry.

The implementation of a few obligatory image-processing algorithms, e.g., atmospheric and topographic corrections, was easy to implement for Landsat images. In a couple of days, GEE could perform all corrections for a country without implementing image tiles options. But that said, in the case of the HKH region, it takes approximately 20 days to create composites. Among the user-defined land cover classes, distinguishing the built-up land cover class was challenging through the random forest algorithm. In this aspect, the newly conceived Normalized Difference and Distance Built-up Index (NDDBI) developed a fusion of OSM and NDVI layers to map built-up accurately (Khanal et al. 2019). Also, NDDBI index takes advantage while negating the limitations on built-up mapping.

6.6.5 Partners' Confidence

It was a challenging task to gain the confidence of the partner agencies to adopt the RLCMS for land cover mapping. It took some time, multiple consultations and training programs to gain their confidence as they had been involved in traditional mapping systems. To ensure that the resultant land cover data would be used by the partners, SERVIR focused on co-development and partnership. But this took a long time since agreements had to be arrived at through the organizational channels of the partner agencies.

6.6.6 Sustainability and Human Resource

Though the RLCMS relies on an automatic classification method and needs comparatively fewer human resources than the traditional image-interpretation-based land cover map production, the future update of land cover data needs a team with an understanding of the RLCMS algorithm which is based on GEE and JavaScript or Python script. At present, the partner agencies lack sufficient GIS and RS professionals with the appropriate background to update the land cover maps. Sometimes, frequent staff turnover in corresponding agencies makes it difficult for sustainable knowledge transfer on land cover mapping. Sometimes, the trained RS staff get transferred to other departments or field offices. Besides, the technical staff at the respective government agencies is engaged in other administrative work which diverts their time from working on the RLCMS.

6.7 Conclusion and Way Forward

The chapter has presented the SERVIR-HKH efforts in land cover mapping of the HKH region. The currently available land cover datasets in the region are not suitable for analyzing land cover changes over time due to the different classification schemes and methodologies used to generate those maps. SERVIR aimed to address this gap and develop a methodology and system to produce land cover maps on an annual basis using the same classification scheme and processing methodology. While addressing the regional needs, SERVIR also focused on addressing national needs that vary and sought to customize the method for producing land cover maps at the national level. The National Land Cover Monitoring System, or NLCMS, was customized for Afghanistan, Myanmar, and Nepal by addressing the specific needs of the national agencies which were co-developing the system with ICIMOD. The system was built and implemented upon the GEE cloud-based platform using Landsat imagery in combination with other thematic layers. The overall process laid great emphasis on collaboration and co-development with the partners to define the land cover typologies, collect reference samples, and validate the data. This chapter has mainly addressed the process, its methodology, and the primary results of the exercise in land cover mapping. In order to enable the partner agencies to produce and validate land cover maps, extensive training and co-development were conducted for sustainability of the system. In the future, more validation programs will be conducted in collaboration with the national partners. Further modifications will also be made to increase the number of classes so that additional requirements are met.

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Chapter 7
Climate-Resilient Forest Management in Nepal

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7.1 Introduction

7.1.1 Ecosystem Degradation in the Hindu Kush Himalaya Region

Forests are important components of livelihood system for a large percentage of the population in the Himalayan region, and they also offer an important basis for creating as well as safeguarding more climate-resilient communities. The HKH region hosts diverse vegetation systems, which could be attributed to the climate variability within the region. However, the region is fragile in terms of land-cover diversity and its association with variable terrain, climate, and socio-demographic interactions. The region is also rich in biodiversity; nonetheless, it is one of the most understudied regions of the world in this regard (Kumar et al. 2019). In addition, in the last few decades, the HKH region has experienced rapid economic, social, and environmental changes owing to unsustainable and haphazard development (Sharma et al. 2019). The Millennium Ecosystem Assessment of the United Nations (MEA 2005) shows that more than 60% of the world's ecosystem services are either degraded or used unsustainably. Stern et al. (2006) have highlighted the detrimental effect of deforestation on climatic conditions, which demands the urgent need for improved management and governance of forest resources to avoid further chronic disturbances leading to degradation. As a matter of fact, higher forest degradation is

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_7

Fig. 7.1 Forests are major sources of timber and fuelwood in Nepal. Photo by Jitendra Bajracharya

occurring in the lower and middle slopes because of heavy anthropogenic activities (Fig. 7.1) (Nandy et al. 2011). In such a scenario, the natural ecosystems are experiencing changes that are adversely affecting the services provided by these pristine ecosystems. Increase in the frequency, duration, and/or severity of drought and heat stress, changes in phenology, increasing pest and fire outbreaks, and changing nutrient dynamics under climate change scenarios are altering the composition, productivity, and biogeography of forests and also affecting the potential and promising ecosystem services as well as forest-based livelihoods. Additionally, vegetation shifts and decline in vegetation productivity have been observed due to the impact of climate change on the HKH region (Wester et al. 2019).

Nepal covers 6.61 million hectares of forest land, representing 44.74% of the total area of the country (FAO 2018; DFRS 2015) and 0.17% of the global forest area (FAO 2018; Keenan et al. 2015). Almost 35% of Nepal's population is dependent on forest resources for their livelihood (FAO 2018), which means that forest degradation and deforestation are major environmental issues for Nepal (Chaudhary et al. 2016). Deforestation is the conversion of forest into another land-cover type while degradation results when forests remain forests but their capacity to produce all ecosystem services is reduced (Lei et al. 2017; MEA 2005; Acharya et al. 2011). In the case of deforestation, the conversion of subtropical broadleaf and lowland sal forests into other land types has been rapidly increasing, while these forests are vulnerable to climate change as well (Thapa et al. 2016).

Degradation can be measured by various approaches, viz. decrease in the canopy density or decrease in biodiversity or increase in the occurrence of invasive plants or a decline in the ecosystem services provided by the forests. Nepal's forest statistics reflects that forest degradation is more critical than deforestation (Acharya et al. 2011) and a major catalyst in promoting forest fragmentation (Panta et al. 2008). Between 1947 and 1980, the annual rate of deforestation in Nepal was 2.7% (Chaudhary et al. 2016), whereas the degradation trend was at 5.57% for the period 1978/79–1994 (Acharya et al. 2011). Studies also show that Nepal's forests are considered to be one of the most vulnerable to the effects of climate change in the HKH region (Lamsal et al. 2017), thereby placing in peril the communities that are dependent on the forests in so many ways (Ma et al. 2012).

7.1.2 Forest Policies and Management in Nepal

In response to the need for a forest management regime, some key policies and legal instruments have been introduced in Nepal: Private Forest Nationalization Act, 1957; National Forest Plan, 1976; Master Plan for the Forestry Sector, 1989; Forest Act, 1993; Forest Rules, 1995; Revised Forestry Sector Policy, 2000; Leasehold Forestry Policy, 2002; Herbs and Non-Timber Forest Product (NTFP) Development Policy, 2004; Forest Policy, 2015; and the Forestry Sector Strategy (2016–25). These policies have been supported by several strategies and action plans such as the Terai Arc Landscape Strategy, 2004–2014; Gender and Social Inclusion Strategy in the Forestry Sector, 2004–19; Sacred Himalayan Landscape Strategy, 2006–16; and the National Biodiversity Strategy (NBS 2002) and Action Plan, 2014. As of 2020, Nepal has 22 protected areas (PAs) distributed across different altitudinal gradients, which have been designed mainly with a focus on wildlife habitat and corridors. Although the earlier policies did not explicitly address the issue of vulnerability of forest and its dependent communities to the repercussions of climate change, the latest policies and strategies have specific provisions related to reducing this vulnerability and promoting/ensuring climate-resilient forest management practices. For example, climate change mitigation and resilience is one of the eight pillars and responding to climate change as a core strategy of the Forestry Sector Strategy (2016–25). Nepal's National Adaptation Plan also has a sector on "forests and biodiversity" to specifically look at the climate change vulnerability under predicted scenarios and identify suitable adaptation options (MoPE 2017). Then there's the model of community forestry which has been in existence in Nepal for four decades and more after the enactment of the National Forestry Plan in 1976. Currently, the number of community forests in Nepal exceeds 22,000, which managing a total area of about 22.37 million hectares involving almost 2.9 million households (Dahal et al. 2017; DoF 2018). These community forests follow the Community Forest Development Guidelines (2014) which empowers the forest user groups to develop their own constitution and management plans, and directs them in implementing activities as per the plans

(GoN 2014). This guideline also includes a mandatory provision on how the revenue that is generated ought to be used—at least 35% of a community forestry group's income should be invested in pro-poor activities and 40% toward the welfare of the forest community (GoN 2014). So far, community forests have been successful in achieving their "dual goal" of ecosystem restoration and livelihood improvement; however, better efforts have to be made to ensure at least 50% participation of women and members of the marginalized communities in decision-making roles; this would tick the boxes of gender and social equality that is part of the UN's Sustainable Development Goals (SDGs).

7.1.3 Importance of Gender and Social Inclusion in Community Forest Management

Community-based forest management (CFM) is considered one of the successful models of community-based forest governance; however, its success depends on several factors—socioeconomic heterogeneity, institutional setting, leadership, property rights regimes, degree of decentralization, community characteristics, technology, and market influence (Cox et al. 2010; Pagdee et al. 2006). Moreover, as things stand currently, while Nepal has taken some important steps in securing gender and social equality, its National Adaptation Plan of Action (NAPA), the Local Adaptation Plan of Action (LAPA), and REDD + (Reducing emissions from deforestation and forest degradation) initiative are not gender and socially inclusive (Gurung et al. 2011).

The United Nations Framework Convention on Climate Change (UNFCCC) first introduced gender to global climate change discussions in 2001, specifying gender equality as a guiding principle in the preparation of adaptation plans for the "urgent and immediate needs" of the least developed countries. It also highlights the importance of women participating in climate change negotiations in a meaningful way. Of all the South Asian countries in the Women's Resilience Index—a tool that assesses the extent to which a country has been able to integrate women into resilience-building efforts—Nepal is the only country where gender has been "mainstreamed" into its climate change decision-making setup, which acknowledges women as a vulnerable group (Agarwal 2010). However, there is an absence of targets for women's involvement within the NAPA, and of the nine specified projects, none is gender-specific (Economic Intelligence Unit 2014; GoN 2010). In our study, we provide more insights into how gender and social inclusion play a role in community-based forest management in Nepal; for this, we have relied on data from three priority districts. We also point out how it is important that the community forest user's groups (CFUGs) have an equal representation of households from all ethnicities and different income categories. The premise of CFUGs asserts that communities or groups of forest users should collectively be engaged in the management of forests (Negi et al. 2018).

7.1.4 *Climate Change Adaptation and Forest Ecosystems*

Understanding the vulnerability of forests and the degradation of ecosystems is the first step toward effectively identifying adaptation and management strategies. The two fundamental response options to the predicted climate change scenarios are mitigation and adaptation. Traditionally, mitigation has been the main focus of those studying climate change, from both scientific and policy perspectives. However, researchers have been underlining the importance of considering adaptation options as a response measure to climate change, along with mitigation mechanisms; the reasons being: Climate change is inevitable; adaptation measures produce more instant benefits; and adaptive actions can be carried out at both local and regional levels (Millar et al. 2007). Hence, the assessment of the vulnerability of forest ecosystems to climate change and the development of a database to identify and support relevant adaptation strategies have been identified as urgent needs.

At present, there is a gap in terms of availability of accurate information on forest degradation and about the impacts of climate change on forest ecosystems; the bridging of this gap could prove crucial in assisting the decision-makers to make more effective plans for managing forest ecosystems. Effective adaptation to climate change depends on the availability of two important prerequisites: information on what to adapt, where to, and how to; and resources to implement the adaptation measures. Ground-based information about the vulnerable systems and the stressors that they are exposed to and the transfer of resources to vulnerable societies to help them prepare to cope with the inevitable impacts of climate change are thus necessary elements of a comprehensive climate policy (Saxon et al. 2005; Parmesan et al. 2013). In this context, in the present study, we introduce the concept of a multi-tier approach that can support effective identification and implementation of adaptation measures.

7.2 Context of Services

A Climate-Resilient Forest Management System (CRFMS) to support decision-making processes at different geographic scales

The district/divisional forest offices of Nepal follow a five-year Divisional Forest Operation and Management Plan (DFOMP), which is used to prioritize the activities of the various divisions. This plan currently lacks a scientific approach to effectively address deforestation and forest degradation as well as the vulnerability of the forests to climate change impacts. To introduce a scientific approach to DFOMP, the Department of Forests and Soil Conservation (DoFSC) is attempting to prepare a vulnerability profile at the district/division level. It would use this profile as a guiding document to identify the hotspots of degradation and vulnerability, and then decide the priorities for that particular district or division. There is also the Hariyo Ban program undertaken by a consortium of four agencies: Cooperative for Assistance and Relief Everywhere (CARE); World Wide Fund For Nature (WWF); the Federation of Community Forestry Users Nepal (FECOFUN); and the National Trust for Nature Conservation (NTNC). The information developed under the CRFMS at the district level could provide important data and information on climate change vulnerability and the degradation of forest ecosystems at the community forest level. This information can add scientific evidence to community-level forest management plans and enhance the decision-making process at the community forest level.

Scope of the service

Theory of change: It is important to define the scope of a service by jointly agreeing with the co-developer and user agencies. It is also important to understand and monitor the impact of the service, which is often done by developing a theory of change (ToC) and identifying impact pathways—and all along adopting the monitoring, evaluation, and learning approach. In the case of the CRFMS service, we and our partners both developed and revised the ToC (Fig. 7.2). Our definition of the ToC revolved around the following elements: zone of project control; zone of project influence; zone of partners' influence; the context; outputs and outcomes; and risks and impacts.

Zone of project control: While developing a service, it is crucial to identify and understand the gap areas through a needs assessment process and to design and develop the service so that the products of the service help in supporting the

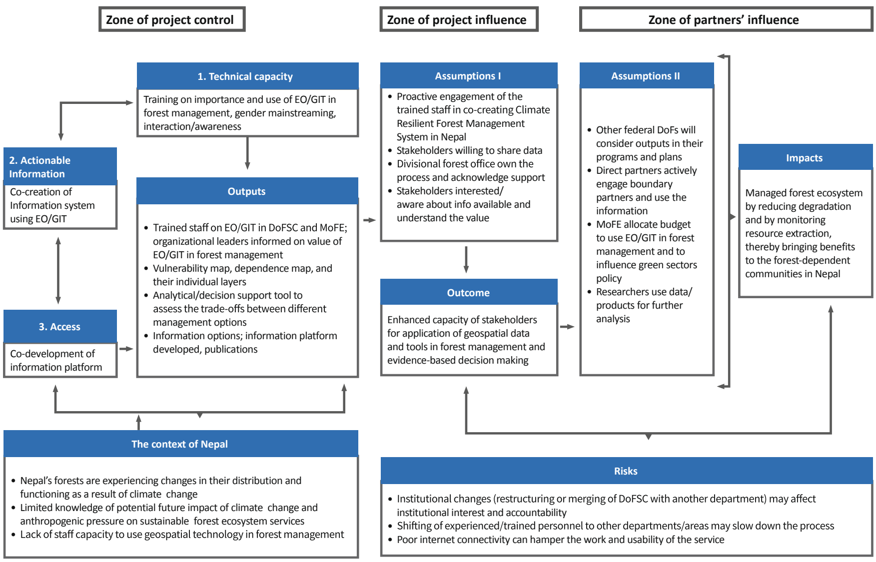

Fig. 7.2 Theory of change for a climate-resilient forest management system

decisions at various scales. Alongside, there's a need to enhance the technical capacity of the implementing partners/co-developing agencies. Co-development of services can be helpful for all the organizations that are involved in the collaborative process, where some stakeholders benefit by getting access to data and information that can help in decision making; while some organizations benefit by getting the thrust to engage with decision-makers for policy-level changes and suchlike. In order to enhance the use of the products that have been developed, packaging them as "actionable information" plays an important role that can help decision-makers to improve their planning and management with precise information, in this case, on the vulnerability of forest ecosystems to climate change.

Zone of project influence: This zone mainly focuses on working together with the partners and involves data collection, data sharing, co-design, and co-development as well as co-implementation of the service. This can be of mutual benefit to both the agencies and adds value to the different products being developed under the service. A proper validation of the products and the information that is generated under the service by the partners is important to assess the accuracy of the products through the decision-makers' lens, which helps in increasing the acceptability of the service to a wider audience. It is also useful to understand the different dimensions, such as gender and social inclusion, in order to explore the socioeconomic linkages and in this case the impacts of forest-related work under the service; this provides an idea about the users of the forest resources and how to bring in sustainable forest management. This also improves the sense of ownership of the service among the partner agencies, which can then enhance the usability of the products by adding to the decision-making capacity of the users.

Zone of partners' influence: This zone focuses on up-scaling and out-scaling of the service to take it to other relevant user agencies—in this case, institutions like the Ministry of Forests and Soil Conservation (MoFSC) and the Department of National Parks and Wildlife Conservation (DNPWC), as well as projects working on the relevant thematic area. Through this scaling approach, we aim to bring a regional dimension to the service so as to get the decision-makers of the HKH region to work on reducing forest degradation and climate change vulnerability in the region.

7.3 Service Implementation

7.3.1 Service Design and Development

To ensure accurate incorporation of user needs, the service was co-designed through a series of user consultations and engagements at different levels. The service-planning process broadly involved three steps: needs assessment, service design, and service delivery. These steps also involved defining the objective and scope of the service, identifying the data and analysis requirement, and defining the features of the application and the design of the system (for more details, see Chap. 2). We conducted a needs assessment workshop with different stakeholders in order to understand their needs in terms of the use of EO and GIT to enhance the decision-making process in natural resource management in Nepal; here, we found gaps in district-/divisional-level forest management, which could be addressed by adding scientific evidence and more useful information on climate change impacts.

This study broadly analyzed four components: climate sensitivity, forest degradation, forest-fire risk, and community forest management (Fig. 7.3). In the climate-sensitivity component, we quantified the impact of observed and predicted climate change on the functioning of the forest ecosystems. We assessed forest degradation by taking into account forest fragmentation and the spread of invasive plants. The forest-fire risk was assessed using more than six different variables responsible for the occurrence of forest fires. In the community forest management component, we explored the role of gender and social inclusion in the management practices of Nepal's CFUGs.

7.3.2 Climate Sensitivity and Degradation Analysis

To analyze climate sensitivity and forest degradation, we used satellite data from MODIS, Landsat Thematic Mapper/Enhanced Thematic Mapper, and the Shuttle

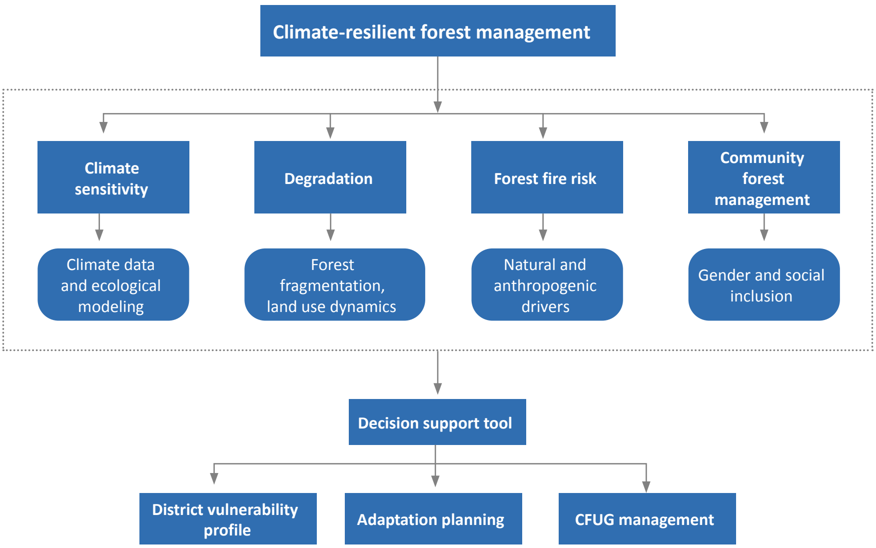

Fig. 7.3 Framework of the CRFMS

Radar Topography Mission (SRTM). In this context, biophysical, climatic, ecological, and socioeconomic data were reviewed and analyzed. For biophysical analysis, we used MODIS-based products like Net Primary Productivity (NPP), Leaf Area Index (LAI), Evapotranspiration (ET), and Forest Fire (FF). As for climatic data, the annual mean temperature and the annual precipitation figures of both current and future periods (RCP 4.5 and RCP 8.5 for the year 2030) were gathered from bioclim datasets. Tree density and species richness were considered as ecological data. And to analyze forest degradation, the following elements were studied: forest fragmentation; distribution of invasive plants; and the demand–supply dynamics of fodder, fuelwood, NTFPs, and timber. The study was carried out in three districts of Nepal located at different altitudinal gradients: Rasuwa in the high-altitude; Lamjung in the mid-hills; and Kapilvastu in the plains.

7.3.2.1 Trend Analysis and Calculation of Climate Sensitivity

The biophysical and climatic data were initially masked by the classified forest cover of the year 2010, and the annual and seasonal linear trend analysis of each biophysical index (ET, LAI, and NPP) was carried out in the R software. Four seasons, namely pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February), were categorized, and the indices' trend was analyzed. Each index (NPP, ET, and LAI) was categorized into five classes using Jenks Natural Breaks in the ArcMap software and reclassified (one to five) at the pixel level. The Jenks Natural Breaks Classification (or Optimization) system is a data classification method designed to optimize the arrangement of a set of values into "natural" classes. A "natural class" is the most optimal class range found "naturally" in a dataset (Chen et al. 2013). The spatial layers of the reclassified indices were then overlaid, and composite values were calculated, through which climate-sensitivity layers were generated. For predicting future climate sensitivity, a model was developed using the R platform for each of the indices, and the spatial raster layers of LAI, ET, and NPP were generated for two climate change scenarios (RCP 4.5 and RCP 8.5) for the year 2030. Future climate sensitivity was calculated from the predicted biophysical indices produced from the developed model. The model was validated by predicting the LAI, ET, and NPP data for the years 2010, 2014, 2015, and 2018, and cross-checked with the MODIS product data for the years 2010, 2014, 2015, and 2018. Furthermore, based on the composite value, the climate-sensitivity classes were categorized into five levels—very low, low, moderate, high, and very high—using the Jenks Natural Breaks Classification system.

7.3.2.2 Assessment of Forest Degradation

The spatial layer of forest degradation was generated based on the demand–supply dynamics of deforestation, fodder, NTFPs, fuelwood, forest fragmentation, and invasive plants distribution.

Ground- and satellite-based data were then used to generate geospatial layers on these parameters, and these were integrated to develop a forest-dependence layer depicting low-, medium-, and high-dependence classes.

The spatial layer for fuelwood supply was generated based on the above-ground biomass map of the landscape, whereas the fuelwood demand map was generated based on the actual fuelwood demand noted in the district forest management plans of the three districts. The data on the demand–supply of NTFPs were generated using the data obtained from the forest management plans of all the districts falling in the study area. The fodder demand map was generated based on the district-wise livestock information and the annual fodder demand for each livestock type; while the grazing supply map was generated based on a grassland map that was created using RS datasets. The spatial layer of deforestation was generated based on the forest dynamics from the years 2000–2010. The forest fragmentation layer was generated based on the land-use and land-cover map of 2010. The invasive plant distribution pattern was developed using the ground locations of 21 dominant invasive plants; this was done via Maxent modeling for the current scenario and for the future scenario of year 2030. All the layers from this climate sensitivity and degradation analysis were aggregated to generate the final layer of climate sensitivity and degradation, which was then divided into five classes to generate the overall layer of forest vulnerability using a classification matrix based on the Jenks Natural Breaks Classification system.

7.3.2.3 Assessing Forest-Fire Risk

We assessed the forest-fire risk using various datasets involving natural and anthropogenic drivers, which was based on a study by Matin et al. (2017). The datasets included: forest type; the average land-surface temperature during the summer season; distance to roads and distance to settlements; altitude; and slope (More details on this can be found in Chap. 8).

7.3.2.4 Integrating Gender Analysis for Enhancing Forest Management at the Community Level

As almost 35% of Nepal's population depend on forest resources for their livelihoods, our study attempted to understand and address the important issues related to gender and social inclusion. The study on gender and social inclusion was mainly focused on CFUGs in western Nepal; it was jointly conducted with a team from Hariyo Ban, a consortium of four agencies working in Nepal, viz. WWF, CARE, FECOFUN, and NTNC. The study aimed to analyze how gender and social inclusion in community forest management vary across the geographical zones in Nepal. We thus hoped to gain important insights into the policy environment and the state of policy–practice interface regarding gender equality and social inclusion in the community forestry sector. Specifically, the study aimed to address the following two major domains by analyzing the analyzing the secondary data/ information at the national level; it also conducted a survey in three districts representing three different geographical terrains (mountain, mid-hill, and plains).

(i) Understanding women's voice and agency in CFUGs
(ii) Allocation of community forest funds for rural development

We utilized the data from the Hariyo Ban I program, which was implemented in the Chitwan Annapurna Landscape and the Terai Arc Landscape during 2010–2015. Due to limited availability of data, only three districts were chosen for the gender analysis: Rasuwa (high altitude); Makwanpur (mid-hills), and Bara (plains). The data were collected in 2017–18 through a questionnaire survey—with 85 parameters—of all CFUGs in these three districts. However, as the data were missing in terms of a lot of parameters, our study focused on only those attributes that had relevance with the gender and social inclusion aspect.

7.3.3 Service Delivery

7.3.3.1 Enhancing the Decision-Making Capacity of Forest Managers in Nepal

We jointly conducted the work in collaboration with the DoFSC with the aim of using science to improve the decision-making process. Regular user engagement was maintained with the DoFSC through frequent meetings and feedback sessions in order to keep the decision-makers updated on the progress of the work as well as on the results obtained during the analysis. The methodology was designed considering the applicability, usability, and scalability of the framework for other countries in the HKH region. The three priority districts were selected considering the differences in their climate, ecology, and socioeconomic conditions; this, we believed, would give us a fair idea about the varying impacts of climate change and about the anthropogenic drivers that trigger this change. The selection of these districts was made after discussions at a consultation workshop in Kathmandu with officers from the various forest divisions of Nepal. Keeping the aspect of usability in mind, we used publicly available datasets for most of the analyses, which comprised of MODIS and other satellite datasets.

The methodology framework of the study was presented to the decision-makers at multi-stakeholder platforms in order to take their feedback and revise the framework wherever needed. This multi-stakeholder forum involved officials from the DoFSC, members of the NAPA team, those involved in the Adaptation for Smallholders in Hilly Areas (ASHA) project, and representatives from WWF, CARE, and FECOFUN. The initial rounds of presentation at this forum focused on finalizing the methodology and data, while later on, the results of the study were presented for validation by the stakeholders. The results highlight the overall vulnerability of the forest ecosystems to observed and predicted climate change and degradation due to the anthropogenic drivers in these three districts.

Climate sensitivity, forest degradation, and forest-fire risk analysis

The feature of climate sensitivity was found to be the highest in Lamjung district, with more than 42% of the forest area falling under the high and very high climate-sensitivity indices. This sensitivity trend is predicted to intensify in the future, where 48% of the current forest area may fall under high and very high sensitivity indices (Fig. 7.4). Moreover, high-altitude ecosystems are predicted to experience more warming than the hills and the plains (Wester et al. 2019). In a 2015 study, Bhatta et al. had observed similar impacts on the forests in Dolakha district, situated in northern Nepal. Our results are in line with results from earlier studies where the forest ecosystems in the high-altitude areas of Nepal have been observed to depict a higher degree of climate change impacts than other physiographic regions in the country (Ebi et al. 2007; Chaudhary and Bawa 2011; Zomer et al. 2014; Chitale et al. 2014; Baral et al. 2018). In the study, out of the three districts, we found Rasuwa facing the highest forest degradation rate, with more than 32% of its forest area depicting high and very high degradation; this could be attributed to the remoteness of its landscape which hinders accessibility to traditional energy sources such as LPG. This might be putting pressure on the forest ecosystems, leading to the extraction of fuelwood. A similar trend was observed in Dolakha in a 2016 study by Kandel et al., while Reddy et al. in (2018) also observed similar trends in forest degradation. In our study, the district of Lamjung depicted 26% high and very high forest degradation areas. In the case of forest-fire risk, it was found to be the highest in Kapilvastu district, with above 52% of it in the categories of high and very high risk. This could be attributed to the plain terrain, dominant broadleaved vegetation, the proximity of agriculture lands, and the easier access to forest areas compared to the mid-hills and the high-altitude areas. So, the possibility is higher of anthropogenic drivers triggering forest fire.

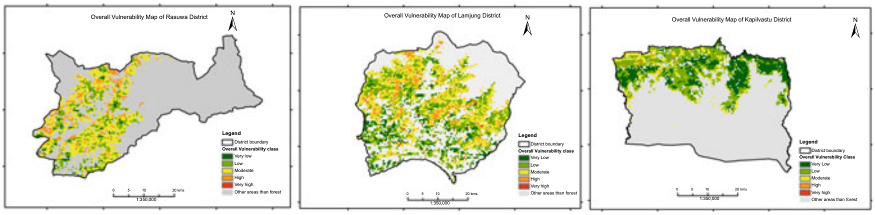

Fig. 7.4 Climate sensitivity of the forest ecosystems in the pilot districts (left to right) of Rasuwa, Lamjung, and Kapilvastu

Gender and social inclusion analysis in the CFUGs

The CFUGs across Nepal may differ in their capacities, interests, and perceptions regarding community forestry (Pandit and Bevilacqua 2011), which might eventually affect the social and environmental outcomes of collective action. Therefore, we attempted to explore the contextual factors that motivate the resource users to participate in collective action. This information could then provide new and important insights into the working of the practitioners who are aiming to improve forest governance by mobilizing cooperation and participation in the management of forests. As per the guidelines for CFUGs, the representation of both women and men in the executive committees should be 50%, i.e., equal. However, our results from the three districts show varied trends of representation of women.

The representation of women in the executive committees of CFUGs in Bara (plains) and Makwanpur (mid-hills) was 47.64% and 46.30%, respectively (Fig. 7.5). This demonstrates that there is still a gap in terms of equal gender representation in the decision-making processes in these districts. However, in the case of Rasuwa (mountain), the percentage of women in CFUGs was 52.89%. The reasons for this could be attributed to higher rates of outmigration of men searching for better opportunity abroad or in the big towns of Nepal; secondly, Rasuwa district is mostly dominated by a homogenous ethnic group called Tamang, in which women have a greater voice in decision making (Acharya and Gentle 2006). As to how this disparity in the gender composition of CFUGs affects forest management practices is a matter for further studies.

Representation of different ethnic groups

Income inequality and ethnic diversity are the two most widely studied heterogeneities that play a significant role in explaining the socioeconomic outcomes of

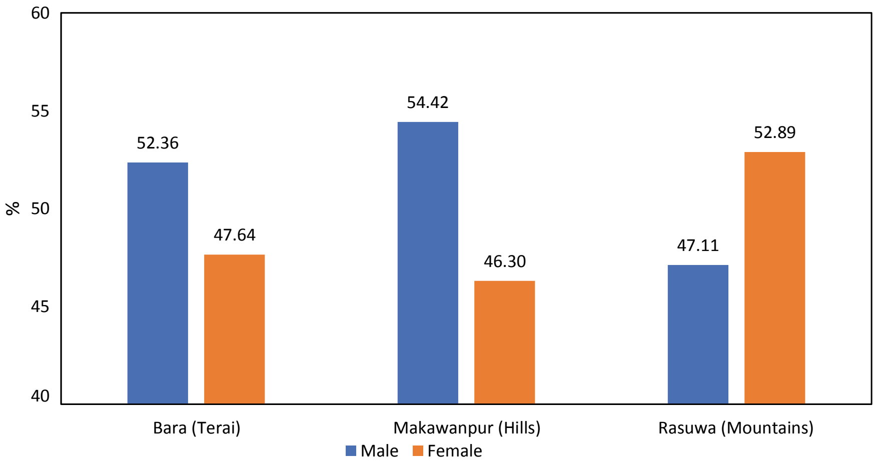

Fig. 7.5 Comparison of community forestry executive committees in terms of gender

collective action (Negi et al. 2018). These and other heterogeneities can shape differences across the users of CFUGs in terms of trust, social capital, and views on the usage and importance of forest, which compel differentiated needs in terms of sustainable collective management.

Since the ethnic composition in Nepal changes along the lines of physiography and accessibility, we expected different variations in composition in the three districts that lie in three different physiographic zones. While in the plains district of Bara, we found almost equal representation (Fig. 7.6)—20% each of Brahmins/Chhetris, Janajatis, Dalits, and Others—as we moved up from the Terai to high altitude, i.e., from Bara to Makwanpur to Rasuwa, we found an increasing representation of Janajatis and a decreasing number of Others.

However, we found a peculiar trend in increasing representation of Janajati and decreasing trend of representation of Other category as we move from Terai to high altitude, i.e., from Bara to Makwanpur to Rasuwa (Fig. 7.6). This highlights differences in the ethnic composition of CFUGs due to reasons linked to physiography. Here, it has to be mentioned that the success of a CFUG lies in being inclusive and accommodating a sufficient number of members from all ethnicities, all income groups, and all genders—such a CFUG is a good and transparent model of governance that provides voice to all different categories (Adhikari and Lovett 2006). Another study has highlighted the fact that generally, rich households prefer more valuable forest products such as timber, whereas the poor households prefer subsistence and commercial forest products as they have limited source of income (Paudel and Sah 2003). However, this is an area that needs further study, and so, through our collaboration with the Hariyo Ban II program, we hope to collect more data on the gender and social inclusion dimension as well as data on the forest management and forestry preferences of CFUGs.

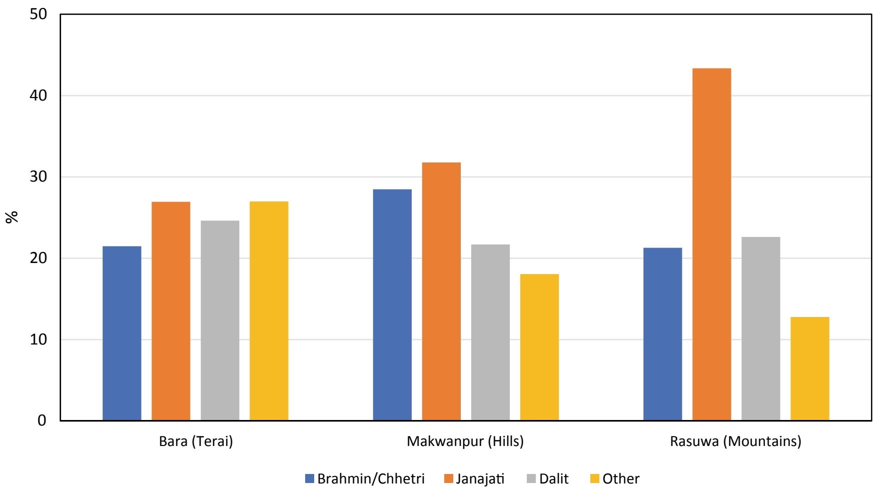

Fig. 7.6 Comparison of community forestry executive committees in terms of ethnicity

Allocation of community forest funds for rural development

Apart from protecting the forest, CFUGs have been mandated to collect revenue from the forest resources and invest in development activities (Angelsen et al. 2005). The sources of revenue for CFUGs are: trade in forest products; membership fee; penalty; and grants and donations from governmental and non-governmental organizations. It is estimated that the annual income of CFUGs in Nepal is more than USD 10 million, with most of it coming from the sale of forest produce, especially high-value items like timber and NTFPs (Pokharel 2010).

Figure 7.7 presents the allocation of funds among CFUGs in the three study districts and how they are spent in areas such as community and forest development, and in welfare measures for the poor.

Forest development activities include silvicultural operations, plantation, and NTFP promotion; community development funds are used for community development, road/foot trail construction, paying the salary of school teachers, building schools, providing drinking water, and securing health/sanitation. The pro-poor welfare measures mainly include income-generating activities. Figure 7.7 shows variation among the three districts in the allocation of funds for these activities. In the case of Rasuwa, more funds—as much as 48% of it—go into forest development activities, while the area of community development receives 31%. Makwanpur, on the other hand, accords high priority to community development, with the expenditure share of this sphere being 65%, followed by funds for forest development at 31%. In contrast, Bara CFUGs allocate more funds—51% of it—for welfare measures that address the needs of the poor; their second priority is forest development activities for which they spend around 27% of funds. All of this

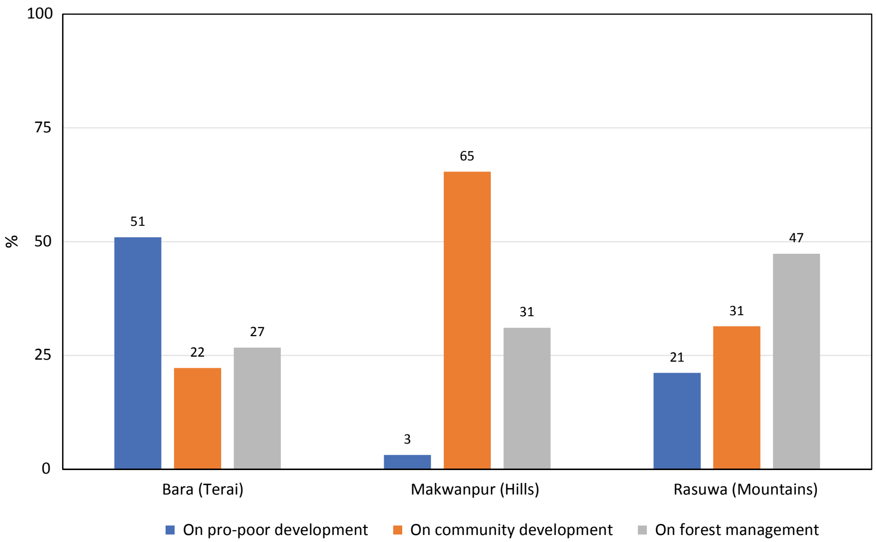

Fig. 7.7 Comparison of community forest fund allocation and expenditure

indicates that the revenue generated at CFUGs is mostly used for collective benefits rather than individual ones. The results presented in this chapter will be further explored in detail in our future work in the area of gender and social inclusion.

Integrated approach for enhancing the resilience of ecosystems

Our results provide important information about the current trends in climate sensitivity and degradation as well as about the predicted impacts on the functioning of forest ecosystems; the results also shed light on the aspect of gender and social inclusion in CFUGs, which needs to be integrated into the planning and management contours of the forest ecosystems in Nepal.

Every five years, Nepal's divisional forest offices prepare and revise forest management and operational plans, which also have a section on climate change adaptation. The findings from our study will be included in this section wherein we will describe the current and predicted climate-sensitivity indices and the observed trends in forest degradation, along with the some six suitable adaptation measures that can be adopted. The framework of the International Union of Forest Research Organizations (IUFRO) on climate change adaptation suggests a list of 144 adaptation options for forest ecosystems across the world. Out of that, we have shortlisted six adaptation options through consultations held in the three study districts; these could be suitable for building the resilience of forest ecosystems not only in these districts, but also for Nepal as a whole. The six options are: forest-fire regulation; grazing regulation; improving stock levels; introducing/enhancing agroforestry; utilizing solar energy; and maintaining forest cover.

The results from our study have been compiled in a web-based decision-support tool (http://geoapps.icimod.org/CRFMS/) that provides user-friendly access to all information on climate sensitivity, degradation, and forest-fire risk from all 77 districts in Nepal. It is also compatible with Nepal's new federal structure, where the districts fall under seven provinces. The tool is open access and includes options to compare any two parameters for the same study area side by side, which should be useful for the decision-makers. The adaptation planning toolbox provides a list of suitable adaptation options that can be implemented to enhance the resilience of forest ecosystems. The decision-support tool also comprises of a module on forest management at the community forest level, which can support decision-makers at CFUGs to understand the trends and predicted scenarios of climate sensitivity, degradation, and forest-fire risk. It can also show them the current patterns of gender and social inclusion in the decision-making processes in the CFUGs. All such tools should further strengthen the capability of CFUGs in the planning and management of forest ecosystems.

7.4 Way Forward

Considering the observed trends and predicted climate change impacts and forest degradation in the countries of the HKH region, it is crucial to incorporate scientific analysis into the planning and management aspects of forest ecosystems. The CRFMS framework follows a "Science into Use" approach that can play an important role in enhancing forest management in these countries. The CRFMS framework is less data intensive, which makes it also suitable for extending its operations to countries outside the HKH region. Building the institutional capacity of user agencies, such as governmental ministries and departments and CFUGs, has been one of our priorities; we believe that partnerships and the active involvement of co-development and user agencies since the conceptual phase of the service is important to ensure a sense of ownership on the products by these agencies. We aim to scale out this framework to the whole of the HKH region, but do not want it to be restricted to this region alone—this framework can be easily implemented in any part of the world. With the advent of freely available satellite data and platforms like GEE, we can apply CRFMS to reduce both time and resources. Ultimately and looking into the future, it is the geospatial tools that are going to be the prime players in decision making, not only in the HKH but also globally.

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Chapter 8
Forest Fire Detection and Monitoring

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8.1 Introduction

8.1.1 Forest Fire Across the World

Forest fire is one of the major global environmental issues, causing havoc in places as disparate as cold Siberia, tropical Amazon, and the temperate HKH region (Fig. 8.1). Recent mega fires in Australia (Nolan et al. 2020), Brazil (BBC 2019), the United States, Greece (CNN 2020; Smith et al. 2019), and Indonesia have not only destroyed ecosystems but have also triggered climate change through carbon emission (Mannan et al. 2017). A rise in global temperature by 2 °C has contributed to increased frequency of forest fire, though only 3% of all forest fires have been caused naturally (Hirschberger 2016)—the majority of them have been sparked off by anthropogenic activities (FAO 2007).

HKH, known as the Third Pole, or the Water Tower, is likely to face an increase in the frequency of forest fires as it is a region sensitive and vulnerable to climate change. The region is currently experiencing an annual increase in temperature by 0.03–0.07 °C (IGES and ICIMOD 2013; Wester et al. 2019; Zomer et al. 2014). Climate change has had an impact on the increasing number of hot and dry days, thereby aggravating the risk of fire (Hirschberger 2016). Also, climate change and forest fire are interrelated and can have an impact on both—while forest fires can cause climate change through carbon emission (Joseph et al. 2009), an increase in

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
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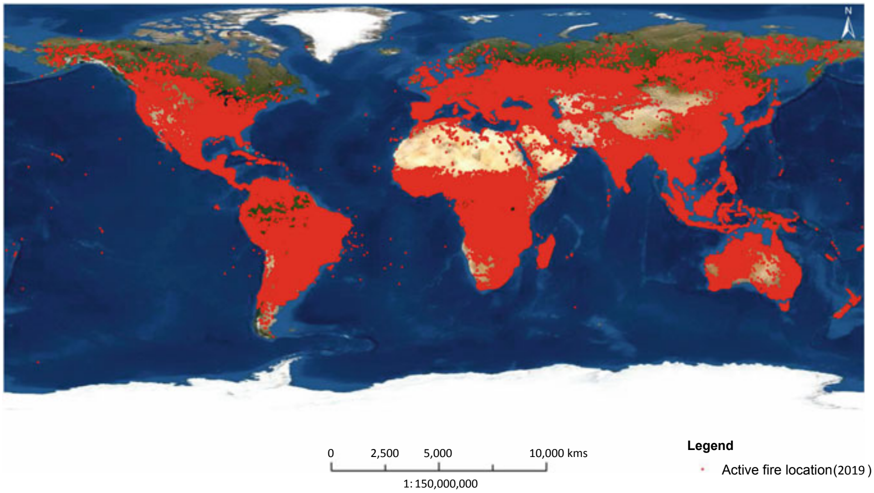

Fig. 8.1 Global distribution of active fires from January to December 2019, as detected by MODIS. *Source* NASA

temperature due to climate change can cause forest fires. Forest fires are a major driver in the destruction of biodiversity and habitats of many endangered species in the region and a key factor in environmental transformation by the infusion of substantial amount of greenhouse gas (FAO 2007; Volkova et al. 2019). Besides, vegetation cover and its moisture content are two of the major factors that significantly influence forest fire as it holds fuel (Ajin et al. 2016; Matin et al. 2017). Areas with dry and dense vegetation are more prone to forest fires than those with moist and sparse vegetation (Stevens et al. 2020). It has also got to be noted that forest fires are beneficial for nutrient recycling and vegetative succession (Chuvieco et al. 2010), but an increase in their intensity and frequency could lead to desiccation and death of trees.

8.1.2 Need for Forest-Fire Risk Mapping and Fire Monitoring

Forest fire not only causes ecological, economic, and material damages but also destroys the forests which are an irreplaceable sink of carbon. In order to support foresters, government authorities, and firefighters in developing efficient fire-risk management plans and to properly monitor and identify the risk areas, it is also crucial to understand the relationship between climate and fire regimes. Forest-fire risk mapping is an essential component in fire management (Sivrikaya et al. 2014) and depends on various factors like temperature, topography, vegetation type, land cover, and distance from settlements and roads (Carmel et al. 2009). A forest-fire risk map helps to identify and locate the vulnerable zones and can assist in formulating a pre-management plan that can help in averting risks (Matin et al. 2017). It is essential to obtain quantitative information on forest fires in order to understand the phenomenon and its spatiotemporal characteristics and manage them (Hua and Shao 2017). Reliable and near-real-time fire detection and monitoring systems can provide vital information to resource managers for prioritizing technical and economic choices for fire prevention and suppression, thereby playing a key role in forest fire management. Several methods and statistical models, like multi-criteria decision analyses (MCDA), Frequency Ratio (FR), Analytical Hierarchy Process (AHP), and machine-learning and ensemble systems, integrated with GIS, have been successfully applied worldwide in developing forest-fire risk maps (Kayet et al. 2020; Naderpour et al. 2019).

8.1.3 RS and GIS Application in Forest Fire Detection and Monitoring

EO data and various RS techniques have been broadly applied in forest-fire monitoring, risk mapping, and in identifying the potential zones. Besides, high-resolution satellite imagery has gained importance in accurately assessing and monitoring the health status of forests (Matin et al. 2017). Since the 1970s, EO satellite sensors have been used to detect changes in the emission of energy. Moreover, a new generation of satellite sensors and Unmanned Air Vehicle (UAV) technology have brought in a superior synergy of present and future RS technology, leading to enhanced monitoring of the extent and frequency of forest fires (Fuller 2000; Hua and Shao 2017; Joseph et al. 2009). Owing to their large-area repetitive coverage and low cost, satellite data sets are helpful in near-real-time fire detection, monitoring, and in the assessment of the burnt areas (Kaufman et al. 1998; Leckie 1990). The availability of high resolutions and more spectral information via Sentinel-2 and Landsat-8 have also widened the opportunities in detecting active fires and in developing new indices for burnt-area mapping (Filipponi 2018; Pádua et al. 2020; Salvoldi et al. 2020; Schroeder et al. 2016). Moreover, fire-monitoring products from MODIS are being used worldwide because of their high temporal resolutions. The MODIS sensors onboard the Terra and Aqua satellites of NASA are commonly used in active forest-fire detection and monitoring across the globe; they provide the location information on the fires occurring across the globe. In 2017, a study by Rahman and Chang (2017) also demonstrated the reliability and robustness of MODIS data in mapping fire severity and the seasonality of vegetational response. With the advantage of EO applications for assessing the fire dynamics, global, regional, and national initiatives have been rolled out, such as the MODIS Rapid Response System global fire maps, GlobScar, the European Forest Fire Information System (EFFIS), Web Fire Mapper, the Canadian Wildland Fire Information System, the Indian Forest Fire Response and

Assessment System (INFFRAS), and Nepal's Forest Fire Detection and Monitoring System (Joseph et al. 2009; Matin et al. 2017). In the case of EFFIS, well-known for its comprehensive monitoring of forest fires, it is based on RS and GIS, and integrated with components like fire-danger forecast, fire detection, forest-fire events, burnt-area maps, land-cover damage assessment, emission assessment, potential soil erosion estimation, and vegetation regeneration (San-Miguel-Ayanz et al. 2012).

8.1.4 Forest-Fire Impacts During the Last Decade in Nepal

In Nepal, active fire incidents and burning days have been increasing annually and more than half of the forest areas experience frequent fires (Fig. 8.2) during the dry season (Parajuli et al. 2015). In Nepal too, anthropogenic activities are considered to be main drivers of forest fire (Khanal 2015). From 2001 to 2019, more than 38,000 fire incidents were reported from Nepal (MODIS archive data: https://earthdata.nasa.gov/firms). The years 2009 and 2016 were the worst, with several disastrous forest fires being reported; in 2016, more than 12,000 community forests in 50 districts were damaged by forest fires, killing 15 people (CIFOR 2017; SERVIR Global 2018). In March 2009, high-intensity and disastrous fires engulfed 48 places in Nepal, including several listed PAs, namely, Langtang, Makalu Barun, Chitwan, Shivapuri-Nagarjun, Bardia and Parsa national parks, Kanchenjunga and Manaslu Conservation Areas, and the Dhorpatan Hunting Reserve (BBC 2012). Earlier, in 1995, about 90% of the forests in Terai had been affected by fires (Sharma 1996), while in April 2009, NASA listed Nepal as a country "most vulnerable to wildfires" having registered the highest number in a day of 358 blazes (The Kathmandu Post 2016). In 2012, more than 70% of Bardiya National Park was engulfed by fire, leading to the loss of 40% of small mammals, 60% of insects, and a substantial number of birds (BBC 2012). In this regard, our study focuses on the efforts in mapping forest-fire risk, and on monitoring and identifying the fire zones in Nepal which could help decision makers in enhancing preparedness and responses during such fires.

8.1.5 Collaborations and Partnerships for Forest-Fire Management in Nepal

Based on the demand from the country partners, in 2012, SERVIR jointly developed a forest-fire detection and monitoring system for Nepal with its Department of Forests and Soil Conservation (DoFSC). In 2019, the system was upgraded in collaboration with the DoFSC in Nepal to include a feedback module for getting information on incidents and damages from the field. Also, a fire-risk analysis and

Fig. 8.2 Forest fires are common during the pre-monsoon season in Nepal. Photo by Birendra Bajracharya

reporting mechanism was incorporated into the system. The DoFSC played a crucial role in the uptake of these products in the planning process in a few districts, starting with Province 1. Besides ICIMOD, other partnerships and programs like the Australia Capital Territory (ACT), Global Fire Monitoring Center (GFMC), Japan International Cooperation Agency (JICA), Korean Forestry Services (KFS), Nepal Forest Fire Management Chapter (NFFMC), Thompson Rivers University (TRU), USAID, and WWF also collaborated with the relevant Nepali agencies in forest-fire governance and management (Sombai et al. 2018). This chapter describes the methodologies and the implementation processes of the fire monitoring system and its components, including about fire-risk analysis and fire-alert monitoring mechanisms.

8.1.6 Objectives of the Forest-Fire Detection and Monitoring System

The forest-fire detection and monitoring system in Nepal, with the help of the DoFSC, aims to support forest officials, local decision makers, stakeholders, and community forest user groups in fire monitoring, analysis, and in the action required to minimize fire impacts. In addition, there's a forest-fire monitoring web tool that supplies visual information on historical forest fires as well as on near-real-time fire incidents and fire-risk areas.

8.2 Methodology

8.2.1 Fire-Risk Mapping

Several indices have been used and suggested to assess fire risks using natural and anthropogenic parameters (Matin et al. 2017; Sivrikaya et al. 2014; Zhang et al. 2014). In this study, we used vegetation type (land cover), elevation, slope, and surface temperature, as the natural parameters, and proximity to settlements and roads as the anthropogenic factors to compute the fire risk index (FRI). The FRI is expressed as shown in Eq. 8.1 (Matin et al. 2017):

$$\mathrm{FRI} = \sum Wi \times Ci \tag{8.1}$$

where *Wi* is the relative weight of a variable and *Ci* is the rating for different classes within each variable.

The relative weights for variables were selected on the basis of literature (Adab et al. 2013; Matin et al. 2017) and the ratings of the different classes for each variable were selected on the basis of historical data analysis (Matin et al. 2017). Higher ratings were assigned to classes with relatively higher occurrence of historical fire incidence within that class compared to other classes.

$$\mathrm{FRI} = 10\ \mathrm{LCR} + 6\ \mathrm{TR} + 4\ (\mathrm{SDR} + \mathrm{RDR}) + 2\ (\mathrm{ER} + \mathrm{SLR}) \tag{8.2}$$

where,

LCR = land cover rating
TR = temperature rating
SDR = settlement distance rating
RDR = road distance rating
ER = elevation rating
SLR = slope rating

The exploratory data analysis method was used while assigning the ratings for the variables.

Vegetation cover and its moisture content is one of the key factors that significantly influence forest fire as it holds the availability of fuel (Ajin et al. 2016; Matin et al. 2017; Roy 2003). Areas having dry and dense vegetative cover are more prone to forest fires than those with moist and sparse cover. The ratings for these variables were assigned as below (Table 8.1), a method adopted by Matin et al. (2017).

Table 8.1 Weights and ratings for different variables and classes

S. no.	Variables	Weight	Classes	Ratings	Fire risk
1	Land cover	10	Broadleaved closed forest	10	Very high
			Broadleaved open forest	6	High
			Shrub land	4	Moderate
			Grassland	4	Moderate
			Needle-leaved closed forest	2	Low
			Needle-leaved open forest	2	Low
			Other land cover	0	Not considered
2	Average summer land surface temperature	6	>30 °C	6	Very high
			25–30 °C	4	High
			20–25 °C	2	Moderate
			<20 °C	1	Low
3	Distance from settlement	4	<1,000 m	6	Very high
			1,000–2,000 m	4	High
			2,000–3,000 m	2	Moderate
			>3,000 m	1	Low
4	Distance from road	4	<1000 m	6	Very high
			1,000–2,000 m	4	High
			2,000–3,000 m	2	Moderate
			>3,000 m	1	Low
5	Elevation	2	<1,000 m amsl	6	Very high
			1,000–2,000 m amsl	4	High
			2,000–3,000 m amsl	2	Moderate
			>3,000 m amsl	1	Low
6	Slope	2	<15%	6	Very high
			15–30%	4	High
			30–35%	2	Moderate
			>35%	1	Low

8.2.2 *Fire Monitoring*

8.2.2.1 MODIS Fire-Detection Process

MODIS active fire products are used worldwide as it provides the location information on fires occurring across the globe. In our study too, MODIS products were used because they have high-temporal, high-spectral (36 spectral bands), and moderate spatial resolutions (250, 500, and 1000 m); they are also freely available compared to other easily available sensors products (Rahman and Chang 2017). Besides, MODIS products are reliable and have proven their effectiveness in fire detection. Each active fire corresponds to the center point of a 1 × 1 km pixel and represents one or more fire incidents occurring within that 1 km^2 area (Fig. 8.3).

The active fire incidents were identified using a contextual fire detection algorithm that classified each pixel of the MODIS swath as missing data, cloud, water, non-fire, or unknown. Firstly, the pixels without a valid value were classified as missing data where cloud and water pixels were identified using cloud and water masks, respectively. The algorithm then looked at the remaining land pixels for identifying fire. For each potential fire pixel, the algorithm used its brightness temperature from the MODIS 4 and 11 µm channels and those of its background non-fire pixels to determine the fire pixels. The size of the background non-fire pixels may vary from a 3 × 3 pixel square window to a maximum of 21 × 21 pixel square window such that at least 25% of the pixels within a window are valid and

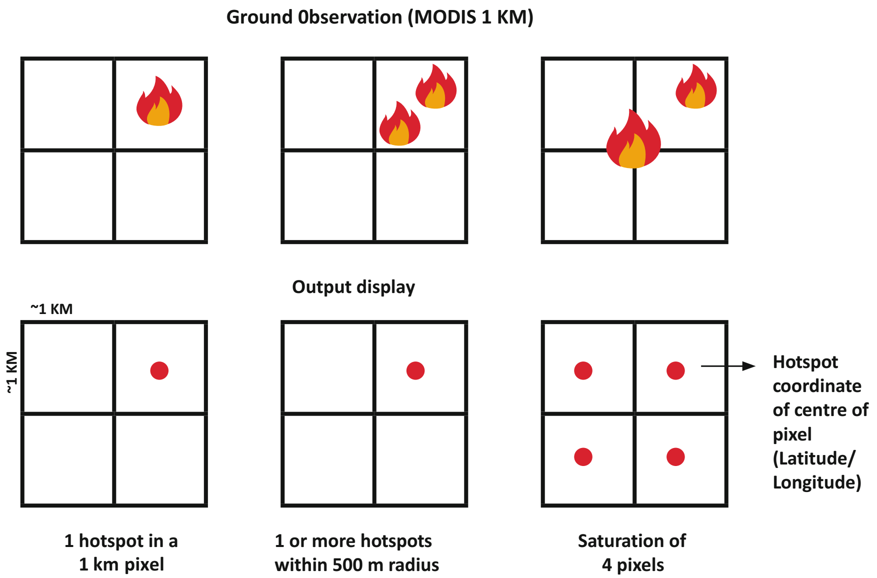

Fig. 8.3 Concept of fire detection in MODIS image. *Source* https://earthdata.nasa.gov/faq/firms-faq

the number of the valid pixels is at least eight. The algorithm identifies a potential fire pixel as a fire pixel if it has a very high brightness temperature of 4 μm or if the brightness temperature difference of 4 and 11 μm depart substantially from that of the non-fire background non-pixels (Giglio et al. 2003).

8.2.2.2 Data Processing Workflow

The MODIS data are downloaded every 24 h from NASA from: https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data. The active fire data are then clipped to Nepal's boundary to know about the fire incidents occurring within the country. Major information related to administrative units (i.e., whether district, rural/municipality, division, subdivision or ward), PAs, land cover, elevation, and slope are then added to the active fire data before they are stored in the fire database (Table 8.2; Fig. 8.4).

8.2.2.3 Web Application for Fire-Alert Dissemination

ICIMOD has developed a web portal/application and this system publishes the stored fire data as a map service so that the locations of fire incidents can be viewed on any given date and filtered at the levels of province, district, subdivision, and protected areas. The portal also includes a damage-assessment form which is only

Table 8.2 List of data used in this study

Name (code)	Platform	Data product	Source
MCD 14 ML (MOD14/MYD14)	Combined (Terra and Aqua)	MODIS/Aqua+Terra thermal anomalies/active fire	https://firms.modaps.eosdis.nasa.gov/download/
Boundary		Administrative boundary (district, rural/municipality, division, subdivision, and ward)	Survey Department, Government of Nepal
		Protected area	Department of National Parks and Wildlife Conservation (DNPWC, Nepal)
Land cover		2010 land cover	ICIMOD (http://rds.icimod.org/Home/DataDetail?metadataId=9224&searchlist=True)
Topography		Elevation, slope, and aspect	http://srtm.csi.cgiar.org/

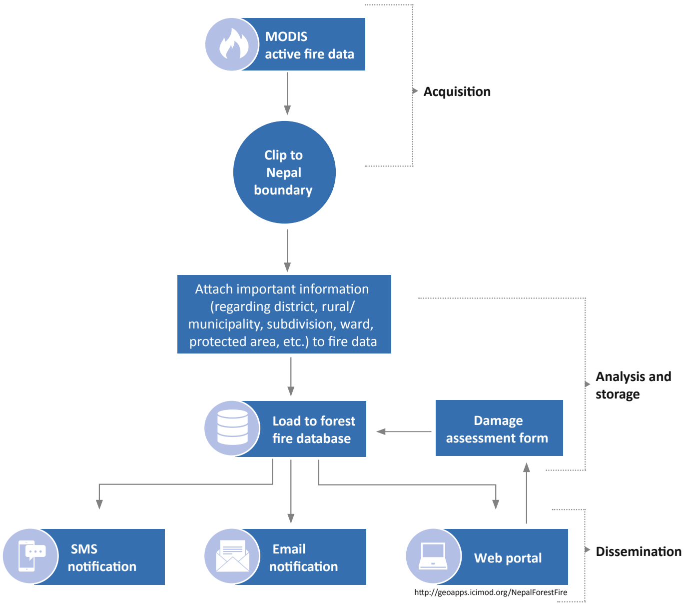

Fig. 8.4 Workflow diagram

accessible to the authorized users. The form is in the Nepali language and it allows entry of data about any damage to a forest or other property by fire, which is then stored in a central database system.

8.2.2.4 Alert Generation and Distribution

When one or more fire incidents are detected in a district, the system sends out SMS alerts containing the location details of those fires to individuals who are subscribed to the SMS fire alert for that district. These alerts, delivered within 20 min of detection, have the ability to reach hundreds of divisional forest Officers and local community representatives from all districts in Nepal. The SMS fire alert contains the following information:

a. District name
b. Location details of individual fires in terms of latitude and longitude
c. Rural/municipality name, and ward number
d. Forest division/subdivision name
e. Protected area identification in case fire is detected within a protected area

The information about all the fire incidents occurring in a district is combined to create one SMS which is then sent to individuals who have subscribed from that district. Due to the restriction on the number of characters that can be sent in one single SMS (160 characters), the fire alert may be received by the subscribers as multiple SMSs in cases when there is a large number of fire incidents within a single district. And to avoid false alarm, the notification on individual fire incidents is included in the SMS only if the "confidence" level of the active fire is greater than 70% and only if it has occurred in forest, shrub, or grassland.

8.2.2.5 Email Alerts

The system also sends email notification on active fires throughout Nepal to all the subscribers, which comprise divisional forest officers and other decision makers in the country. These notifications contain the following detailed information on individual fires:

a. Location details of individual fires in terms of latitude and longitude
b. District, rural/municipality name and ward number
c. Protected area identification in case fire is detected within a protected area
d. Elevation (in meters)
e. Slope (in percentage)
f. Confidence (in percentage)

8.2.2.6 Fire-Incidence Maps and Feedback from Field

The system allows registered users to download maps with forest fire incidents on any given day. The fire-incidence maps were generated on the basis of fire occurrence data of over 50% confidence level recorded by MODIS. To avoid wrong identification, incidence levels of less than 50% were filtered out. The system also allows the user to view and select any information provided on this web platform.

A mobile application, "Nepal Forest Fire Detection and Alert", has also been deployed to support citizens in reporting forest fires in Nepal. Through the use of this application, members of CFUGs and forest department officials can now respond more quickly to fire dangers. Moreover, a damage assessment form has been integrated into the web-based system that allows DoFSC officials to capture information on reported fire incidences, estimated damages, and on fatalities.

8.2.3 Temporal Distribution of Forest Fires in Nepal

A total of 38,248 active fires with a confidence level of 50% or more were recorded in Nepal by MODIS sensors from January 2001 to December 2019. The maximum number of fire incidents occurred in the year 2016 (Fig. 8.5), which were almost 15% of all the total fire events that took place from 2001 to 2019; the second highest (9%) took place in 2009, followed by instances in 2019 (8%). A study by

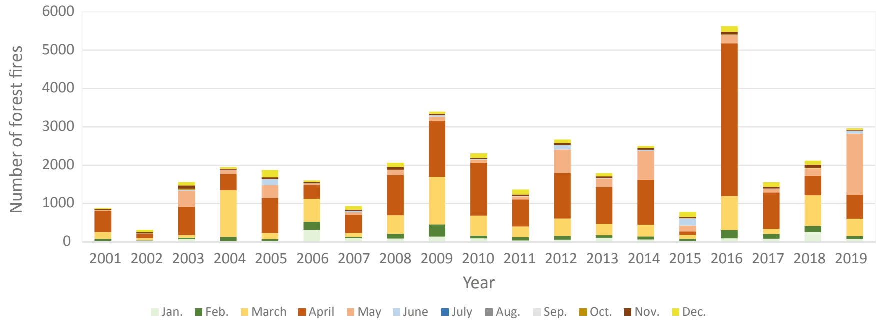

Fig. 8.5 Annual and monthly forest fire in Nepal

Bhujel et al. (2017) reflects the increasing trend of forest fire in the last two decades, with the plains of Terai recording the highest density and the highest burnt area per square kilometer in 2016. And, the years 2009 and 2016 were considered as drought years as they experienced severely dry weather during the summer. Besides, an analysis of the monthly patterns of forest fires from 2001 to 2019 shows that usually such events start during the winter months of October to January and reach the peak in April when more than 45 of forest fires occur. We also observed a change in the peak month of occurrence of forest fire, which is shifting from March to May, perhaps attributable to phenological changes and the vegetation's responses to climate change. Here, it has to be noted that negligible or almost no fire incidents took place between June and September which constitute the monsoon season.

About 71 of the fire incidents occurred outside the PAs, whereas 29% took place inside the Pas (Fig. 8.6). Within the PAs, approximately 75% of fires occurred in national parks, followed by 13% in buffer zones (Fig. 8.7). In analyzing the forest fires from the years 2001 to 2019, we found more instances of fires—almost 20% each—in Bardia and Chitwan national parks, followed by Parsa National Park at 15% (Fig. 8.8). All these three national parks are located in the lower elevation in

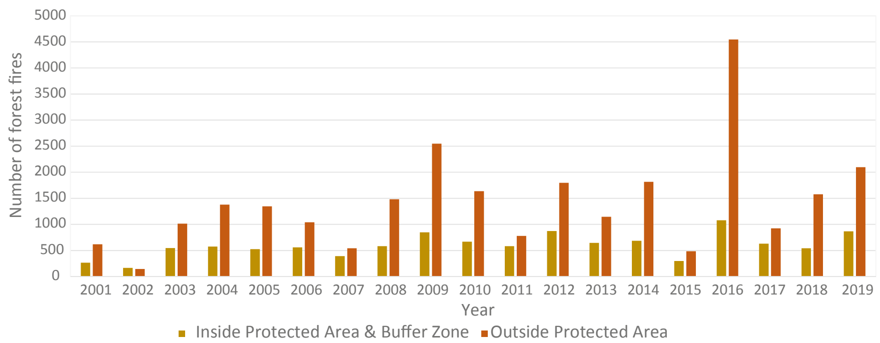

Fig. 8.6 Distribution of forest fire inside and outside protected areas (2001–2019)

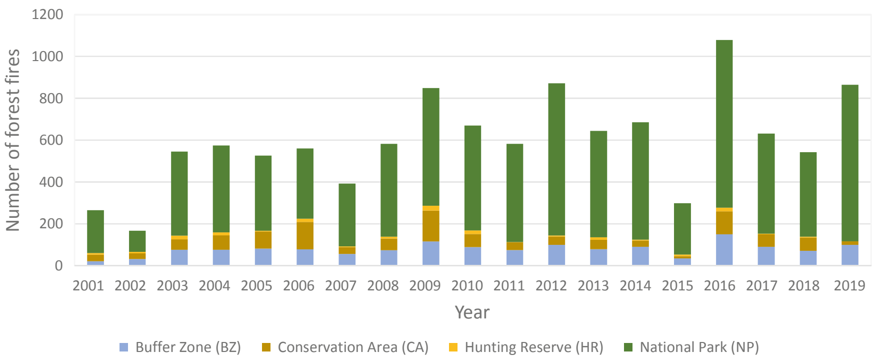

Fig. 8.7 Distribution of forest fire in different types of protected areas (2001–2019)

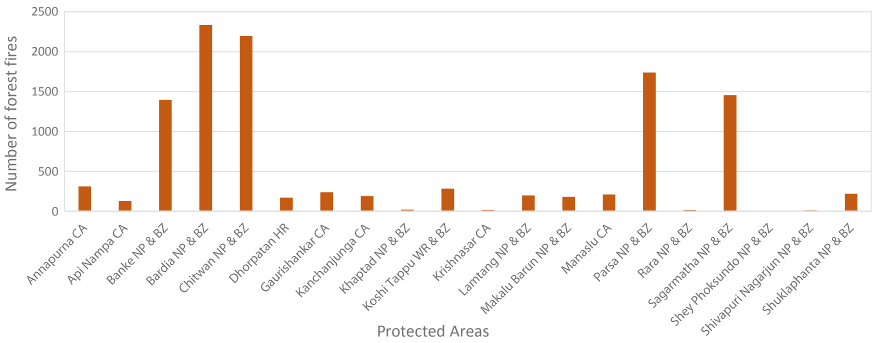

Fig. 8.8 Total number of forest fires in different protected areas (2001–2019)

the Terai region which has a higher temperature and lower humidity compared to other regions in Nepal. Moreover, the forests in these parks are mainly composed of tropical and subtropical species that shed large quantity of dry leaves, which results in a larger accumulation of fuel (Kunwar and Khaling 2006). Further, the analysis of fire incidences inside and outside the PAs revealed that the number of such incidents was two to three times higher outside the PAs. The fact that PAs practice conservation and management strategies and there is less anthropogenic activities inside them might be the reason that they don't record more incidents of fire.

Out of the five physiographic zones of Nepal, Siwalik zone recorded the highest number of fire incidents, approximately 35%, followed by the middle mountains (26%), Terai (21%), and the high mountains (13%), and the least in the high Himalaya. More than 80% of the broadleaved forests in the country lie in the middle mountains and Siwalik, the reason these areas record the highest number of fire events. The tropical broadleaved forests experience substantial leaf fall in the summer season, which results in the piling up of dry leaf litter, fueling successive

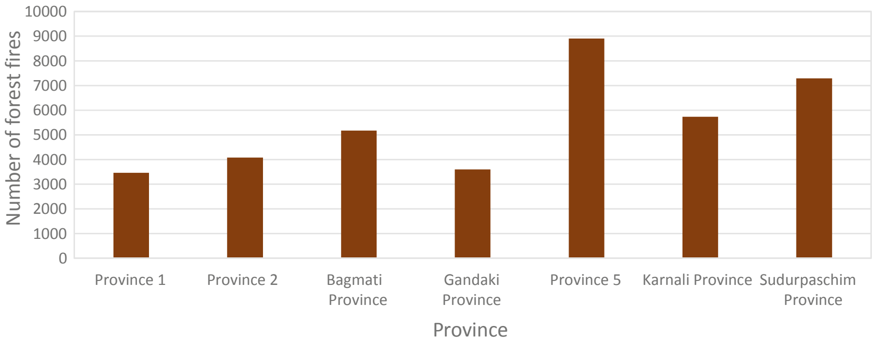

Fig. 8.9 Province-wise forest fire from 2001 to 2019

and extended incidents of fire during summers (Matin et al. 2017). In the forest-fire trend analysis, out of the seven provinces, Province 5 showed the highest number of fire incidents of about 23%, followed by Sudur Paschim (Province 7) of 19%, Karnali (Province 6) of 15%, Province 3 of 14%, Province 2 of 11%, and Gandaki and Province 1 of 9% (Fig. 8.9).

8.2.4 Characteristics of the Location of Fire Occurrence

The majority of the forest fires were reported from low-elevation areas (up to 1,000 masl). More than 85% of the fires were recorded below the elevation of 2,000 masl, of which 65 occurred below 1,000 masl. Only a negligible per cent (about 1%) of fire incidents were recorded above 4,000 masl. Besides elevation, slopes also have an effect on the distribution of forest fire. A significant number of fires were recorded in plain lands with less than 5% sloping and in moderate lands with 15–35% sloping. A negligible number of fire events were noted in the steep-land areas (>50% slope).

8.2.5 Forest-Fire Risk Zone and Vulnerability

Six major driving factors, namely, land cover, average summer land-surface temperature, distance from settlement, distance from road, elevation, and slope were taken into account while analyzing the forest-fire risk zone. The study demonstrates that out of 77 districts, 12 districts fall into very high forest-fire risk zones and 11 districts in the high-risk class (Fig. 8.7). Most of the districts located in Terai and Siwalik zones are in the very high and high-risk classes.

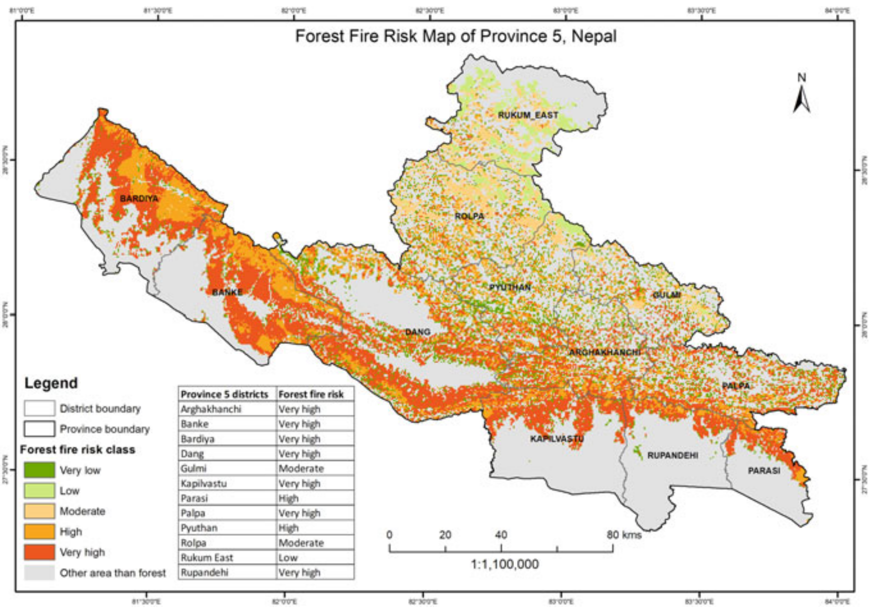

Fig. 8.10 Forest-fire risk map of Province 5

The province-wise forest-fire risk analysis reflects that the forest area (about 4,000 km^2) in Province 5 is more vulnerable and falls under the very high-risk category (Fig. 8.10), followed by Bagmati Province (≈3,400 km^2) and Sudurpashchim Province (>2,600 km^2); whereas Province 1 is in very low fire-risk class (Fig. 8.11).

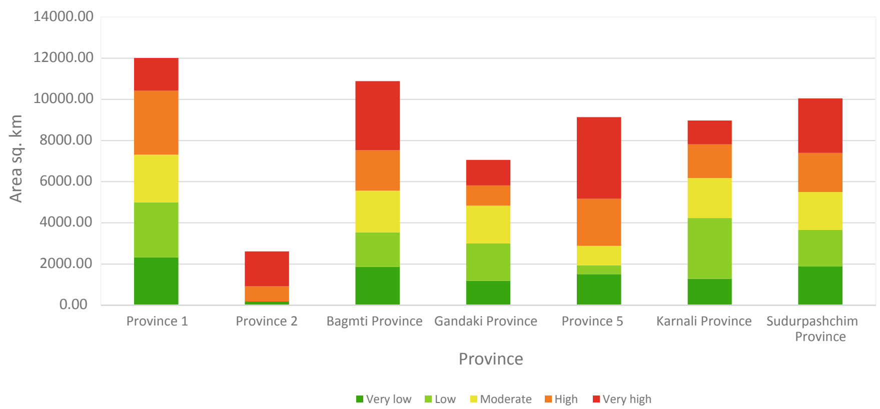

Fig. 8.11 Province-level forest-fire risk classification

8.2.6 Forest-Fire Monitoring System in Nepal

Nepal's forests exhibit a high level of threat from fires, which occur predominantly during February to May, with its peak being mid-April. In this regard, it is imperative to understand the temporal pattern of the fires in order to be better prepared and disseminate timely fire-alert messages. In a bid to record the forest-fire risk areas in Nepal, a SERVIR-HKH team and the DoFSC co-developed a map showing the fire-risk areas zones in Nepal. This map depicts the risk levels in all the 77 districts of Nepal—from very low to very high risk—which can help decision makers in prioritizing forest management activities, especially with regard to reducing the risk of forest fires. The map is placed in the forest-fire control room in DoFSC, which is the main monitoring station in Nepal that reports the occurrence of forest fires to the relevant agencies. Following hands-on training by the SERVIR-HKH team, the DoFSC has prepared province- and division-level maps to help the relevant stakeholders in reducing forest-fire risks at various spatial scales. Besides, based on a request from DoFSC, a forest-fire alert and monitoring web tool (http://geoapps.icimod.org/NepalForestFire) has been customized which contains a form that mentions, apart from other details, the extent of damage caused by such fires. The web tool is available both in Nepali and English languages (Figs. 8.11 and 8.12). This tool not only provides real-time information on the occurrence of forest fires but also sends SMSs and emails to officials from all forest divisions, subdivisions, and to the members of community forest user's groups across the country. In the year 2019, more than 300 fire-alert SMSs were sent to district officials in the months of April, May, and June; more than 200 SMSs were sent in the month of May alone, with Salyan district receiving the highest number (68) of fire-alert SMSs in that month (Fig. 8.13).

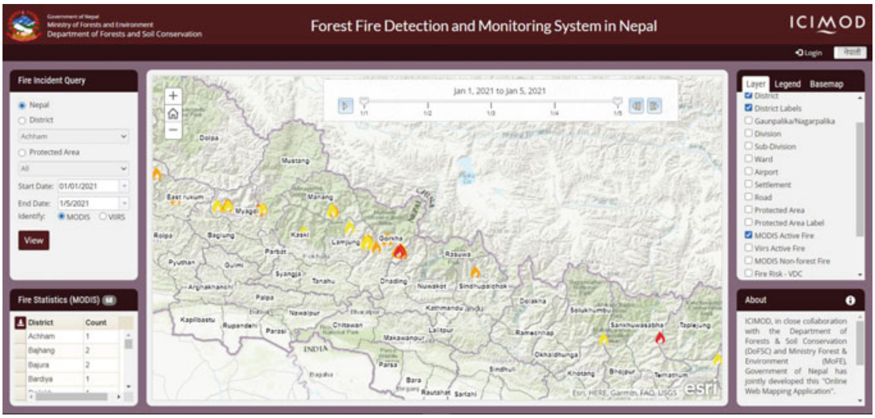

Fig. 8.12 Forest-fire detection and monitoring web tool

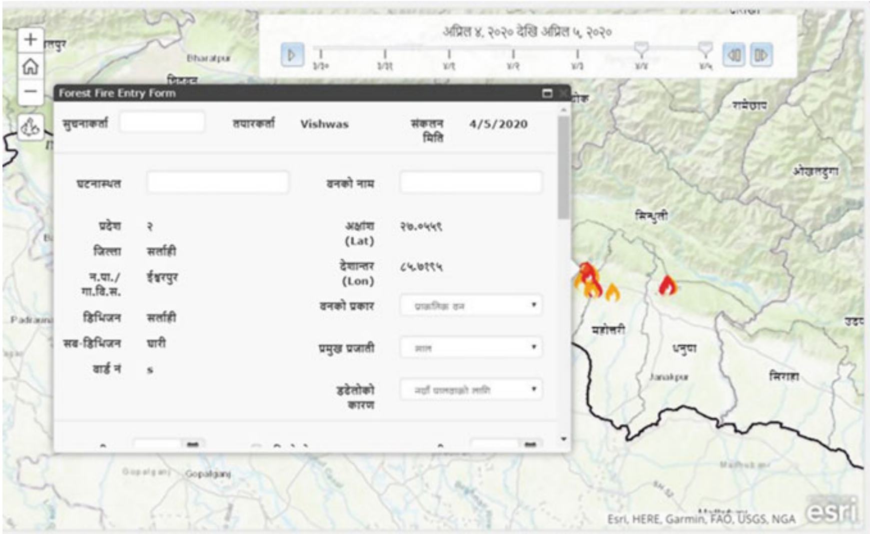

Fig. 8.13 Forest-fire damage-assessment form

8.3 Deployment of Forest-Fire Detection and Monitoring System

The system has been upgraded since it was operationalized in 2012, and recently, it has also incorporated data from the Visible Infrared Imaging Radiometer Suite (VIIRS). Besides, a mobile application, “Nepal Forest Fire Detection and Alert”, has also been deployed to provide wider access to citizens to report on forest-fire incidents in Nepal. Earlier, the lack of mobile networks in remote parts of Nepal had hindered communication, but the situation has improved since 2016–17. It is also essential that the database of mobile numbers gets continuously updated as sometimes the relevant staff gets transferred to other places. Also, the validation and confirmation of forest-fire alerts are important. The brighter side in the whole context of fighting forest fires has been that there now exists a strong collaboration with DoFSC and there’s increased awareness about forest fires and the role of RS and GIS in tackling the problem.

8.4 Limitations and Challenges

The following points ought to be considered regarding information on active fire:

a. The active-fire data provide only the location information, i.e., center of the fire pixel of 1×1 km area and it shall be used as alert over 1 km^2 area, not the exact point.
b. There are some problems with fire alerts:
   - Sometimes, due to the coarse resolution of the fire pixel, a fire occurring in one district may be falsely reported as one occurring in a neighboring district.
   - Certain small-duration fires may have been extinguished by the time the subscribers get the fire alert since currently, the alerts are sent after about two to four hours of the satellite's passing.
c. Certain fires may be missed out because they are of a smaller size or smoldering, and they were not occurring during the satellite's passing.
d. SMS alerts may not reach the subscribers on time because of some technical issues faced by Nepal Telecom.

8.5 Capacity Enhancement of Partners

Several training programs on forest-fire detection and monitoring systems have been provided to the DoFSC staff with the aim to enhance and strengthen the DoFSC's institutional capacity in generating information on important attributes such as forest-fire risk, fire occurrence, and damage to the forests. Training materials, hands-on exercises, and flyers have been developed on how to use the forest-fire monitoring system and web application. The DoFSC staff are now well acquainted with fire-monitoring system and web application. They have also become skilled in identifying the vulnerable zones, which has helped them in minimizing the impacts of forest fire.

8.6 Way Forward

With the help of fire-risk zonal maps and other forest-fire monitoring tools, the forest managers can now easily track the fire-risk areas and develop strategies in fire management. This has also enabled efficient and effective decision-making in minimizing the impacts of fires as well as in allocating resources to the province, district, or area that face high fire risk.

More users should be brought into the firefighting system—from the forest directorates in the seven provinces and the 84 divisional forest offices in the country. The MoFE, DoFSC, and the province-level forest directorates should work in unison and reach out to all levels of administration and community to tackle the menace of forest fires. This can be facilitated through appropriate policy and program support, dissemination of information, and the monitoring of activities on the field. There's also a strong case for regional cooperation in the firefighting arena whereby all the relevant agencies are not only made aware of the seriousness of the problem but also of the fact that fires know no boundaries.

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Chapter 9
Enhancing Flood Early Warning System in the HKH Region

Karma Tsering, Kiran Shakya, Mir A. Matin, Jim Nelson, and Birendra Bajracharya

9.1 Introduction

Flooding is a chronic natural hazard with disastrous impacts that have magnified over the last decade due to the rising trend in extreme weather events and growing societal vulnerability from global socioeconomic and environmental changes (WMO/GWP 2011). Such unprecedented change is manifest in the increased severity and frequency of climate-induced hazards that are intensifying disastrous consequences, in particular, flood disasters. While vulnerable nations grapple with the flip side, it has globally-inspired collective interest and resolves to anticipate extremes, invest in building resilient societies and economies, and make proactive interventions. Catastrophic floods impact tens of millions of people each year and cause significant infrastructure damage around the world. The situation is getting worse due to increasing population, urbanization, and economic development in hazard-prone areas (Etienne et al. 2019). Floods are among the most frequently occurring and deadly natural phenomena, affecting on an average 520 million people a year (UNESCO 2007). Almost half the people killed in the last decade (as a result of natural disasters were victims of floods, which also account for about one-third of economic losses (CRED/EM-DAT 2020). Globally, flash floods are among the world's deadliest natural disasters accounting for almost 85% of the flood incidences with the highest mortality rate among different classes of flooding and resulting in significant social, economic, and environmental impacts (Fig. 9.1). Flash floods are also difficult to forecast compared to riverine (floodplain) floods due to their rapid onset and as they occur in smaller basins due to intense and incessant rainfall. Also less frequent but more catastrophic are the flash floods

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_9

triggered by natural and artificial dam breaches which have far more disastrous impacts on lives and properties.

Bakker (2009), analyzing flood statistics on the Emergency Events Database (EM-DAT) and the Dartmouth Flood Observatory databases for the years 1985–2005, showed that 75% of the countries affected by riverine flooding share this event with other countries, and that flooding in transnational river basins, globally, accounts for about 30% of the casualties and that it affects almost 60% of the population. A basin-wide approach linking upstream catchments with downstream riparian countries is recognized as a key consideration when dealing with trans-boundary floods at all phases of the flood-risk management cycle.

9.2 Flooding Trend in the HKH

The HKH region is no stranger to catastrophic floods. Seasonal, riverine, and flash floods are frequent occurrences along the rivers and tributaries in the HKH. Figure 9.2 gives an overview of the devastating flood events experienced by the HKH countries over the last 70 years, as registered in the database of the Center for Research on the Epidemiology of Disasters (CRED). Every year, destructive floods occur at one place or the other across the HKH bringing about untold suffering and often accompanied by loss of lives, livelihoods, and severe damages to property.

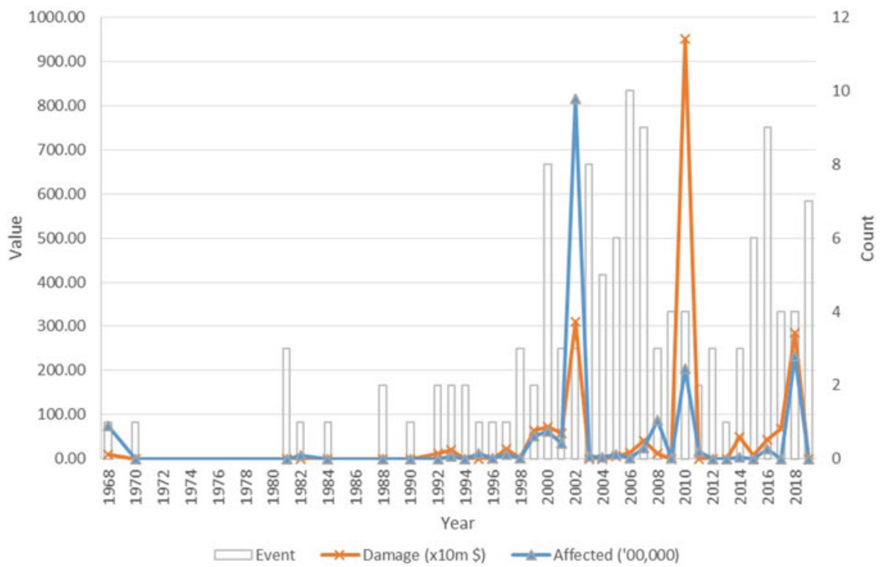

Fig. 9.1 EM-DAT historical records of flash-flood events [D. Guha-Sapir]

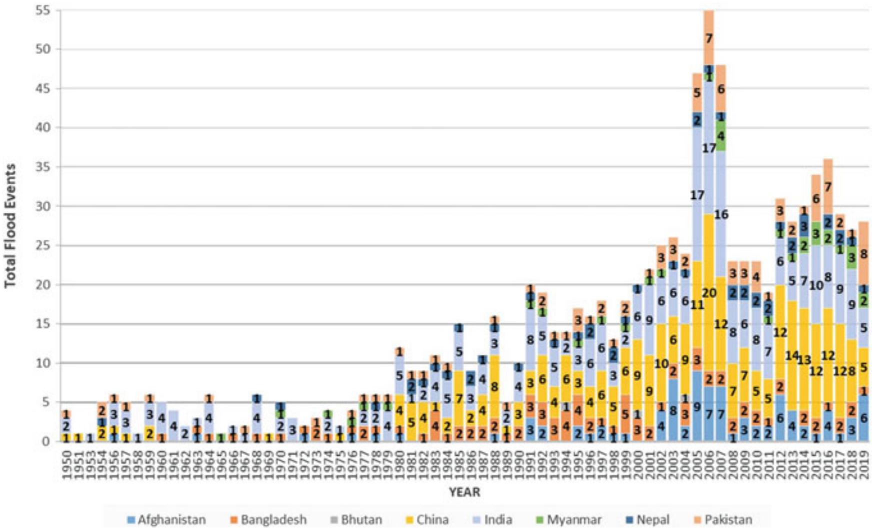

Fig. 9.2 Total number of flood events in the HKH region by member countries from 1950 to 2019. *Data source* EM-DAT: the OFDA/CRED International Disaster Database—www.emdat.be—UCLouvain—Brussels—Belgium

Bangladesh is probably the most flood-prone country in the world. Approximately, 20–25% of Bangladesh's territory gets inundated during every monsoon season, and at least 50–70% of the country's territory is exposed to intermittent extreme flooding which has far-reaching negative impacts on the national economy (Akhtar Hossain 2003). Being a lower riparian country, about 25% of the rivers in Bangladesh are of the transboundary type, with more than 93% of the drainage basins located outside its national territory. Flash floods from the surrounding uplands from April–May are followed by episodic inundation during the monsoon, with some of them persisting for months. A very recent event of consequence was the monsoonal flood of July 2019 that caused 119 human fatalities, directly affected 7.3 million people, and displaced an estimated 308,000 people in the districts of Jamalpur, Kurigram, Gaibandha, Sylhet, Sirajganj, Tangail, Sunamganj, Bogra, and Bandarban. Approximately, 584,000 houses were damaged or destroyed, including 6,641 km of road and 1,275 bridges. The same monsoonal system also wreaked havoc in Nepal and India. In Nepal, it caused several floods and landslides across 32 districts, leaving 117 dead, several injured, and many unaccounted for; close to 12,000 households were displaced, mostly in the worst-affected districts of Rautahat, Mahottari, and Siraha. Across India, 1,326 people died and over 1.8 million people were displaced (GDACS 2019).

Summarizing from the results and findings of past studies on the flooding situation in the HKH region, Shrestha et al. (2015) concluded that floods in the region cannot be totally controlled and that efforts should be directed towards reducing flood vulnerability and mitigating impacts through improved flood risk management by providing end-to-end flood forecasting and warning services. Flood events cause far more suffering and bring economic burden on the poor and the marginalized communities in the mountains since the socioeconomic situation and lack of political voice invariably condemn them to the most vulnerable sites for sustenance. The study concluded that on an average, 76 flood disasters occur annually in the region, accounting for thousands of deaths and millions of affected people. The breach of the Koshi barrage in the 2008 flood event was a textbook case during which millions were displaced across Nepal and Bihar, and hundreds of lives were lost, along with millions worth of Indian rupees' in damage and destruction.

Generally, the HKH region is vulnerable to flooding during the summer monsoon season; however, its western part does experience significant and sometimes devastating pre- and post-monsoon floods associated with mid-latitude westerly storms. Pakistan has suffered massive flood disasters in recent decades causing huge economic impact and human suffering. When normalized to the respective country's economic strength and population size, Nepal, Afghanistan, and Bangladesh show higher socioeconomic impacts of flooding (Elalem and Pal 2014).

Improvements in flood forecasting and the ability to communicate actionable information to those at-risk have substantial lifesaving and monetary benefits. But the benefits will accrue only if early warnings lead to early action, which can very much depend on the credibility and available lead-time of the warning information. Communication and dissemination are consistently being identified as the weakest links in the flood management chain despite tremendous growth in information products and increasing demand from the stakeholders and affected communities. There is a real need for targeted and tailored communication of flood information to reach the local level.

The targets set under the Sendai Framework for Disaster Risk Reduction (SFDRR) and the Sustainable Development Goals (SDGs) advocate flood early warning systems (EWSs) as a flood-risk management measure (UNISDR 2006). However, despite widespread recognition (UNDRR 2004; WMO 2013; Pappenberger et al. 2015; Thielen del Pozo et al. 2015), the operational status, benefits, and costs, and the challenges and trends associated with these systems have still not been fully understood so as to garner concrete support and commitment for wider adoption and upscaling to multi-hazard capability (Perera et al. 2019).

9.2.1 Perspective on the Current State of Flood Management—Issues and Challenges

The way people deal with floods determines whether water remains a life-providing element or becomes a destructive force against human life and economic development. Traditionally, flood management has focused on reactive practices largely relying on flood control through structural and non-structural measures. Amongst many structural and non-structural measures, flood forecasting and early warning have proven to be effective in reducing flood risks through better preparedness and resilient responses. But there is an increasing urgency to address the challenges of factoring flood-hazard risks in water management, increasing multidisciplinary approaches, improving upon the information for an integrated strategy to prevent disasters, reducing vulnerabilities, and building community resilience, thereby enabling all-inclusive participation (Fig. 9.3). Adopting an integrated approach has been a paradigm shift in flood management, away from the dominantly reactive engineering interventions of flood control. While it is possible to anticipate and prepare for some floods, there are also others that take place in a totally unexpected manner. While we cannot necessarily eradicate all the threats, we can nonetheless become better aware of their likelihood and potential impacts regardless of them being perceived or real. The greatest challenge is and will continue to be, the sustainability of efforts in dealing with flood events as complacency could set in once the memory of recent occurrences subsides under a prolonged lull.

Effective flood detection is analyzed by accurate estimation of water-level thresholds that identify specific hazard levels along an entire river network. The estimation of suitable exceedance thresholds is a key task in the flood early warning system, where alerts are determined by the ratio between streamflow estimates and reference thresholds (Alfieri et al. 2019). But real-time simulation of hydrologic and hydraulic flow processes is expensive because of the computing resources and

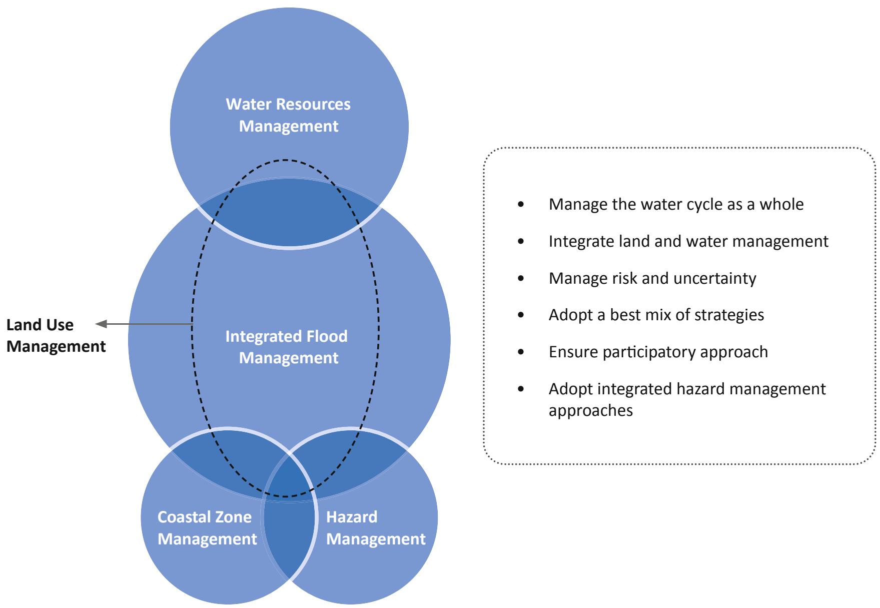

Fig. 9.3 Key elements of an integrated flood management model. *Source* APFM, WMO (2009)

entails a steep learning curve to build the necessary human capacity to set up and run the models. As an alternative, pre-simulated scenarios and matching processes are often employed to anticipate flood events and determine the consequences.

According to Perera et al. (2019), challenges in flood management arise from several factors related to the inadequacy in the observing and monitoring networks on the ground, poor integration of remotely sensed and satellite Earth observations, and the inability to assimilate outputs of numerical models into developing a common operating picture in flood management. The expenses involved in the acquisition of technological know-how and scientific knowledge, and other related financial issues are the primary reasons for not investing sufficiently in the critical facilities and generating actionable information in strategizing flood management systems. The appreciation for prevention and preparedness is still very low among the decision makers faced with competition for development priorities in a situation where the resources are scarce.

9.2.2 State of the Science in Flood Forecasting

The flood-forecasting process includes executing hydrological models with observed and predicted hydro-meteorological data to obtain information on river discharges and translating the predicted streamflow into simulated river-water stages. The water levels in the river channels are then assessed in the context of flood-recurrence intervals to decide on the warning levels for dissemination to areas likely to be exposed to imminent flooding hazards. Unless early warnings inspire early actions to mitigate risks, they are unlikely to deliver the anticipated socioeconomic benefits that can accrue from even the best and robust of flood prediction and early warning systems.

To start this dissection from a broader and longer perspective, it all began with relentless efforts in predicting the ENSO (El Nino-Southern Oscillation) phenomenon, which added a whole new dimension to the issue of weather and climate predictability. Since it has a dominant influence on the seasonal and annual variability of floods and droughts in South Asia, the focus was initially on precipitation forecasts as a proxy for hydrological extremes. But the relationship between extreme precipitation and extreme flooding is nonlinear and not the best of indicators. So, the improved predictability of ENSO impacts, along with recent advances in prediction science and forecasting tools, has opened up vast opportunities to provide reliable forecasts and early warnings on disastrous floods. One such approach is the dynamic seasonal river-flow outlook of the Global Flood Awareness System (GloFAS-30 Days and Seasonal: http://www.globalfloods.eu 2020). GloFAS products are now widely used by almost all the national hydromet services in the HKH region as the benchmark guidance for daily forecast routines and seasonal outlooks on flood situations.

Modeling the catchment hydrologic response to the predicted meteorological forcing in space and time defines the flow characteristics that will be evaluated as flood or not based on a set of exceedance thresholds. Flood forecasting is done to detect flood with sufficient actionable lead time to protect lives and properties through better preparedness and response measures. Modeling science has evolved to fit the circumstances in which outputs are applied and matched with the available and accessible data required to configure and run the models. A more recent approach is toward tailored, purpose-built prediction models nested within broader flood-forecasting frameworks (Fakhruddin 2010; UNDP 2018; WMO 2011). Such configurations provide flexibility in the choice of an appropriate model, chain different models with scalable and interoperable computing infrastructure, and single-window user-interface platform for dissemination.

From the operational perspective, flood forecasting is precisely about providing legitimate, credible, and reliable information to the right people at the right place, and time in a manner comprehensible and actionable (Perera et al. 2019). Observations and research findings have evidenced that natural hydroclimatic variability and imperfect understanding of the physical processes cause the issue of uncertainty in flood forecasting. This uncertainty increases as forecasts are translated into potential impacts in terms of inundation extent and early warnings. However, recent technological developments in hydrologic modeling, exponential growth in computing power, satellite earth observation, and communication advances continue to improve forecast accuracy and warning lead time. As science narrows the knowledge gap between mesoscale and convective processes, there is a real hope of developing and operationalizing a class of scale-independent forecasting and warning schemes.

9.2.3 State of Flood EWSs

Any holistic EWS should necessarily include the formulation of warning, the issuance of warning, the reception of and response to warning, and finally the feedback to those who developed and issued the warning in the first place. Formal or informal early warning systems have existed for centuries. Traditional approaches to flood early warnings have been based on the comparison of measured water stages with predetermined "threshold levels". Current EWSs utilize water-level sensors placed at strategic locations along flood-prone drainage segments to monitor river stage and relate to predefined thresholds in order to trigger appropriate levels of warnings. Generally, different agencies are involved in the production, issuance, and response to warnings, with no single organization responsible for an end-to-end flood early warning service. More recent warnings employ scientific advances in the knowledge and understanding of hazards and the natural and human-induced processes that result in hazardous situations. Warnings are now essentially based on forecasts, projections, scenarios, and trends as a result of tracking a selected, explicitly identified set of hazard and threat indicators. These indicators must not only be reliable but also possess the ability to discriminate between levels and degrees of urgency, severity, and the certainty of the threats unleashed under every possible onset of flood events. The recent introduction of the predictive uncertainty concept enables probabilistic decision thresholds using multi-model and multi-run ensembles.

EWSs are meant to be integrated within the wider disaster risk-reduction strategy, rather than be a stand-alone solution. A flood EWS can protect livelihoods and properties and save lives only if people act on the warnings. The core purpose of any people-centric EWS is to empower individuals to act in sufficient time and in an appropriate manner to minimize as much as possible the loss and damage to people, property, and the environment. UNDRR (2006) recognizes four interrelated elements (Fig. 9.4) in a comprehensive and effective EWS; they are risk knowledge; monitoring and warning service; communication and dissemination; and response capability. But they must be grounded in good governance and supportive institutional arrangement that underscore multi-hazard readiness, community participation, and social inclusion.

EWSs do not always fit the circumstances under which they are considered as solutions to flood-risk management, nor are such systems without pitfalls in the setup and operation. Early warning dissemination and distribution rely on good telecommunication networks that may not be accessible in every flood-prone area of interest. Besides, purpose-built alternatives could turn out to be technically and economically infeasible, especially if the flood-affected sites happen to be in remote and inaccessible locations. As with everything pertaining to the future, early

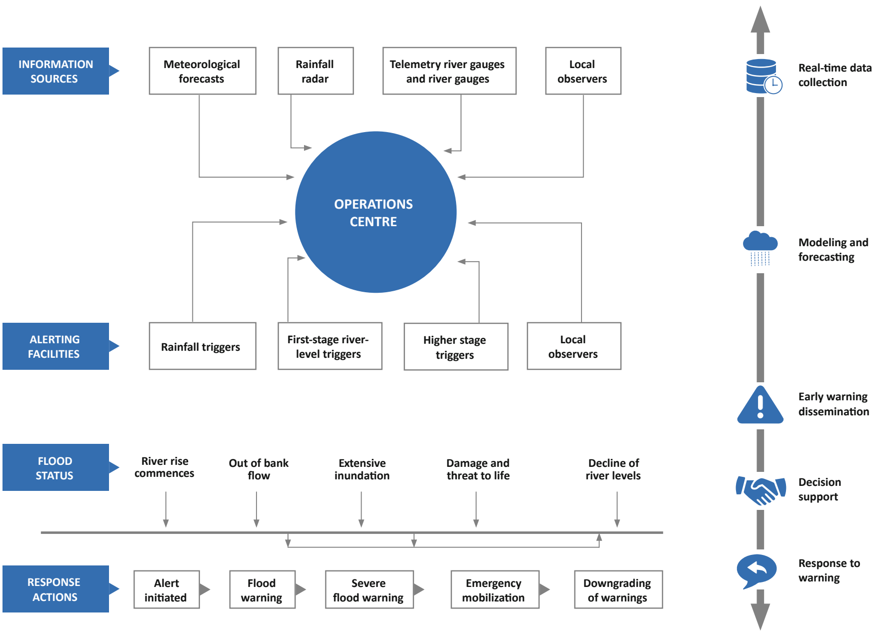

Fig. 9.4 Framework of a common approach in flood early warning (adapted from WMO 2011)

warnings inevitably involve handling uncertainties in ways that enable a risk-informed decision-making process. Similarly, floods cannot be predicted with absolute certainty because of imperfect understanding about the physical process and because of aspects of randomness that are inherent in the evolution of the process. Such limitations can sometimes result in false alarms which besides incurring unnecessary costs and inconveniences, can actually diminish trust in the system, thereby rendering it ineffective. Although a typical flood early warning system is devised around water-level sensors placed at sufficient distance from the impact zone, the warning lead time is usually extended, based on model predictions. Good quality real-time observational data are used for model calibration and the runs, but these may not be readily available or accessible. These problems continue to frustrate efforts in making EWSs more robust and credible despite significant advances in science, technology, and related approaches.

9.3 Societal Values of EWSs

9.3.1 Situational Awareness and Preparedness

The achievement of desired societal benefits is predicated on the effective communication of early warnings to those exposed to flood risk. A lingering challenge has been the integration of systems operating at different spatio-temporal scales to provide a more coordinated, comprehensive, usable, and effective early warning information. Early warnings of a flood event, combined with early warnings of underlying societal problems and processes, can lead to a strengthening of resilience and a reduction in vulnerability (Glantz 2009). EWSs are the stabilizing accessories of a nation's social, political, and economic systems; it may be tenuous at times and full of surprises, but never dispensable. It empowers governments to protect citizenries and maintain political stability. The benefits of EWSs lie in our appreciation of the knowable surprises. A case in point is the fact that while information on the flood-prone areas is known beforehand, the timing of the flood, its magnitude, and the extent of its impact may be difficult to determine accurately. Based on the historical experience of flooding vulnerability, every government must be guided by the precautionary principle to sensibly invest in operational flood EWSs in order to protect lives and properties, and reduce losses.

As noted above and to again emphasize the criticality, an effective EWS typically consists of a credible forecasting structure, a reliable communication service, and a proactive response mechanism. However, an EWS is not a static contraption but must evolve and improve with changing times and technology as we continually witness new normals due to climate, economic, and demographic changes. Almost all countries operate one form of forecast and early warning or the other, using different hydrological models, hydro-informatics, and computing infrastructure of varying strengths and capabilities. Very few actually operate basin-wide systems, limiting such services to within respective territorial boundaries and weak mechanism for information sharing. All countries follow the WMO convention of a single national voice for warning dissemination with authority delegated to single agency, but the cooperation between countries is weak and ineffective.

National and local governments and disaster-emergency managers have long identified the need for a fully functional early warning system to disseminate information well in advance of a flood situation. While it is not possible to stop natural floods from occurring, the impacts can be mitigated and the associated risks to lives and properties can be reduced through effective early warning systems. However, early flood warnings are situational and contextual in that their formulation and issuance are scale-specific and often isolated from the consequent outcomes in terms of reception and response from the intended users. Without exception, forecast-based EWSs are produced to increase the warning lead-time and the level of certainty of an event of a certain magnitude occurring at a certain time and place. Early flood information can also be verified through comparison with other forecasts that are freely available at national and regional levels. The co-benefits are numerous, ranging from stronger cooperation and better partnership networks and information exchange.

9.3.2 Loss and Damage Reduction

The costs of flood disasters from damage and loss are difficult to estimate and it is even more difficult to assess the socioeconomic and monetary benefits of EWSs in terms of the costs avoided or reduced. As a general practice, a typical cost-benefit analysis would involve knowing the index of loss and the cost of damage, as well as the cost of developing and operating an EWS, besides the cost associated with the use of an EWS service (Perera et al. 2019). An effective EWS can deliver significant benefits at all stages in the flood-risk management cycle and reduce human fatalities and injuries, loss of livelihoods, and damage to properties and infrastructure. Continuous operation of EWSs can actually lead to a better understanding of the flood situation and greater awareness about the risks that are involved. The importance of building resilience and the need to implement preparedness measures will receive greater attention as communities and authorities gain deeper insight into the urgency, severity, and the certainty of the flooding information provided by EWSs. There is also the potential to realize substantial benefits in terms of reduced costs in relief, recovery, and reconstruction if warnings are issued with sufficient lead time for preparedness action.

9.3.3 Extending the Lead Time

Warnings must be conveyed in a timely manner, particularly in vulnerable and remote locations, using clear information expressed in non-technical language; they should also identify and specifically mention the areas at risk, as well as explain the potential losses, all within certain time frames (UNDRR 2006). In most of the countries in the HKH region, warnings are formulated and issued without standard protocols in terms of the technical format, dissemination mechanism, and communication channels; so, difficulties emerge in the understanding of the message and in setting up appropriate response mechanisms. It is also crucial to emphasize that early warnings need to be followed through with early actions, but this is easier said than done because response plans are not framed to account for every warning situation. However, the situation is a lot better now, with better access to ground and satellite data, as well as due to global and continental-scale forecasting systems that predict floods over a longer lead time with a credible probabilistic scale to supplement national services. Longer lead times obviously lead to better preparedness and response measures (Smith et al. 2017). One such example is the Copernicus Emergency Management Service (CEMS), GloFAS (http://www.globalfloods.eu/), that couples state-of-the-art weather forecasts with a hydrological model to provide global flood overviews. Resolving GloFAS to local scales at finer resolution entails downscaling the global outputs through the integration of spatially granular information about the basins of interest and weather parameters. Through the SERVIR-HKH initiative, the countries in the HKH region are now equipped with customized systems to access global information through local applications. Moreover, the platforms that host and process cloud-computing and EO data are now available for running local-area models and performing complex analysis under various programs (Soille et al. 2016).

The next few sections are devoted to the efforts at ICIMOD to develop products and services aimed at bridging the knowledge and technology gaps in generating streamflow forecasts which can enhance the regional and national capacity to provide reliable and effective flood early warnings and thereby reduce risks and minimize loss and damage. The approaches leverage recent advances in scientific knowledge and cutting-edge computing technologies in flood prediction to push the limits of predictability in terms of timing, magnitude, and forecast horizons.

9.4 Flood Early Warning System (FEWS) Services and Tools in SERVIR-HKH

The SERVIR-HKH EWS service includes an operational 10-days streamflow forecast application based on the GloFAS direct runoff field routed with RAPID (Routing Application for Parallel Computation of Discharge) model (David 2019). The gridded flow predictions are downscaled to vector river network. The forecast is meant for larger rivers at designated locations agreed by the partner agencies in Bangladesh and Nepal. For Bangladesh, the forecast is implemented for 17 boundary rivers and in the case of Nepal, for all its large rivers. A customized web-based information portal has been developed to communicate warnings to the intended users. The service also includes 48–54 h of short-fused flood predictions from a quantitative precipitation forecast field generated through HIWAT (High Impact Weather Assessment Tool), an extreme weather prediction system targeted at small “flashy” rivers mainly in Nepal and north-eastern Bangladesh.

9.4.1 Flood Prediction Tools

The streamflow prediction tools (SPTs) based on HIWAT and ECMWF (European Center for Medium-Range Weather Forecasts) present an unprecedented opportunity for an integrated end-to-end flood forecasting system that can extend the currently possible lead times (Snow et al. 2016). Both the tools are based on ensemble runs using perturbed physics and the sampling probability distribution of initial and boundary conditions in order to constrain uncertainties and provide a probabilistic forecast for improved decision-making. The tools were developed through scientific collaboration between ICIMOD, the NASA Applied Science Team (AST) from Brigham Young University, the NASA Marshall Space Flight Center (MSFC), and the Jet Propulsion Laboratory (JPL).

HIWAT is a severe convection-allowing weather forecasting system that predicts extreme weather phenomena spawned by localized convective instabilities like thunderstorm, lightning, windstorm, hailstorm, and cloudbursts. The HIWAT system (Chap. 12) was implemented on a cluster at the SERVIR Global computing infrastructure and runs during the pre-monsoon and monsoon seasons from April to September every year. A visualization application runs on an open-source Tethys platform (Swain et al. 2016a, b) in ICIMOD to disseminate the forecast. HIWAT is also a severe-weather ensemble model based on the Weather Research and Forecasting (WRF) community model with a 12 km outer and 4 km nested domain positioned over South Asia. It provides daily 48 h forecasts with 1800 UTC (Universal Time Coordinate) initialization. The 12-member ensemble is created from varying planetary boundary layers and microphysics schemes that are convection-permitting. Different GEFS (Global Ensemble Forecast System) members are used to initialize each ensemble member. The model outputs are available on an hourly frequency and post-processed to generate information on severe weather products, one of which is the accumulated precipitation thresholds, the probability matched mean of which is used to force the RAPID model for flash-flood forecasting.

In the case of ECMWF-SPT, river discharge is simulated by RAPID in routing the ensemble surface run-off fields processed by HTESSEL (Hydrology Tiled ECMWF Scheme for Surface Exchange over Land) of ECMWF’s (Balsamo et al. 2009) coupled land-atmosphere IFS (Integrated Forecast System). RAPID is a matrix version of the Muskingum method (David et al. 2016) that produces 51 possible evolutions of streamflow in a 15-day forecast horizon. Further, a deterministic RAPID routing is run offline using run-off fields forced by ERA-Interim near-surface variables in order to derive the seamless streamflow climatology. Then the discharge values of the daily annual maxima are extracted and submitted for extreme value analysis so as to estimate the corresponding discharge exceedance thresholds for selected return periods. These models have been extensively evaluated at several observational points across Nepal and Bangladesh. The ensemble streamflow predictions were also evaluated against the discharge-proxy simulations for the same period, which was taken from the simulated discharge climatology obtained by using ERA-Interim/Land run-off as a forcing element.

The lack of transboundary information often makes it difficult to increase the lead time on flood forecasting in downstream countries like Bangladesh. The dissemination of the warning information for timely access and use by communities is also important to get maximum return from these services. In Bangladesh, the hydrological models for an effective flood early warning system suffer from a lack of upstream data. The quality of these models can be enhanced through land-surface and hydromet data from upstream and boundary stations. In the meantime, in Nepal, given the understanding about the limitations with its in-house forecasting model, there is an interest to consume forecasts from these tools as part of the decision-support system. From a series of consultative processes, it has become apparent that there is a particular interest in the HIWAT-based RAPID model in the prediction of short-fused floodings in flashy catchments. More particularly, since the present models are not sensitive enough to predict the rapid onset of floods, extreme weather events like flash floods, triggered by intense precipitation events, are a serious threat to the local communities.

9.4.2 Hydro-Informatic Workflow

The modeled predictions are consumed using intuitive web-based interfaces so as to extract and visualize flood-forecast data for specific areas of interest via customized web applications. Further localization is enabled through the implementation of REST API (Representational State Transfer-Application Program Interface) services (Souffront Alcantara et al. 2019). The hydro-informatic workflow links the web applications with the back-end cyber infrastructure for model computation to access and display the forecast information sought by the users. A geospatial preprocessing approach (Snow et al. 2016) is used to generate information on the river network, weight tables, and RAPID parameters in order to convert the grid-based HTESSEL run-off fields and route through the vector-based river network. The HIWAT hydro-viewer and SPT are the interactive web applications that have been developed using the Tethys development and hosting platform (Swain et al. 2016a, b). The workflow resides in the cloud to compute model forecasts and host geospatial web services. The overall geospatial preprocessing and routing process of how the forecast information is delivered to the end users is illustrated in Fig. 9.5.

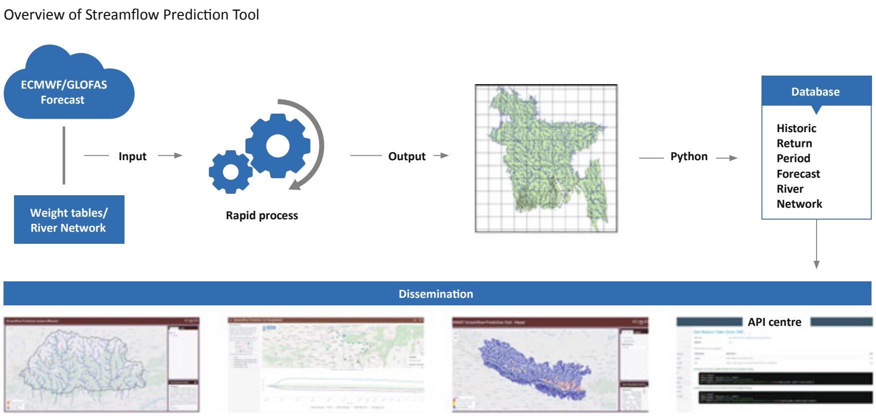

Fig. 9.5 Schema of the parallel computing framework and web-based dissemination of forecasts and warnings incorporated into the SPT web application

The web-based prediction services include an operational 15-day flood forecast based on ECMWF, and HIWAT based flash flood tool that forecast out to 48–54 h. Both tools use RAPID model to route direct runoff through drainage networks encompassing designated locations agreed by the partner agencies in Bangladesh and Nepal.

The implementation of a forecast-based EWS requires both human and computing resources to support not only the development of the system but to operate it and maintain it through time. What sets apart the SERVIR flood forecasting services from the mainstream systems is the simplification of complex processes without sacrificing the power of emerging science and technological innovations. Users can now concentrate on making informed decisions in managing flood risks without being distracted by the tedious and costly routines in collecting and processing data, setting up and running models, forecast production, and dissemination. The disconnect and seeming incoherence between the components of the service-value chain no longer constrains reliable and timely service provision.

9.4.3 Implementation of Innovative, Customizable Tools

Customized web-based applications for Nepal and Bangladesh were developed and deployed in collaboration with ASTs to retrieve model outputs and visualize the information products required by the users. The HIWAT-based flash flood tool is also customized and hosted as an online application using the same Tethys platform. These tools have undergone several iterations in response to user comments and feedback on the interfaces. The SPT workflow for hydrological modeling using RAPID is also in the process of being transferred to the ICIMOD server, and once this migration is completed, the latent time from model run to ingestion and product rendering by the web application is expected to reduce significantly.

The web-based SPT system was co-developed with the help of ICIMOD's regional partners. The system is now being enhanced with inputs from the partners. It has also been customized in order to accommodate the requirements of the partners and also for them to have an easy access to the system. The system is in-built with analytical tools by which the user can interact with the system through the website. Upon clicking the desired river section, the user can view the forecast charts for that section, along with information on the rate of discharge at any particular time of the day. The SPT web application facilitates user access to forecast information in an intuitive and comprehensible format (Fig. 9.6). The major components of the chart are:

- High-resolution forecast (10 days)
- Standard deviation and mean, maximum, and minimum flow forecasts (generated through 51 ensemble forecasts, inclusive of the ensemble control run)
- Information on two-, ten-, and twenty-year return periods.

The table below the chart provides the possibilities of the return period discharge in percentage, using 51 ensemble data sets from the model. The user can also view the model historical data set starting from 1980 and also the flow-duration curve; besides, there is an option to download the data set.

The enhancement in the system is to indicate the high-risk river section with proper color codes related to the return periods. The risk-to-river section is updated daily to provide near-real-time information and show the condition of the river at

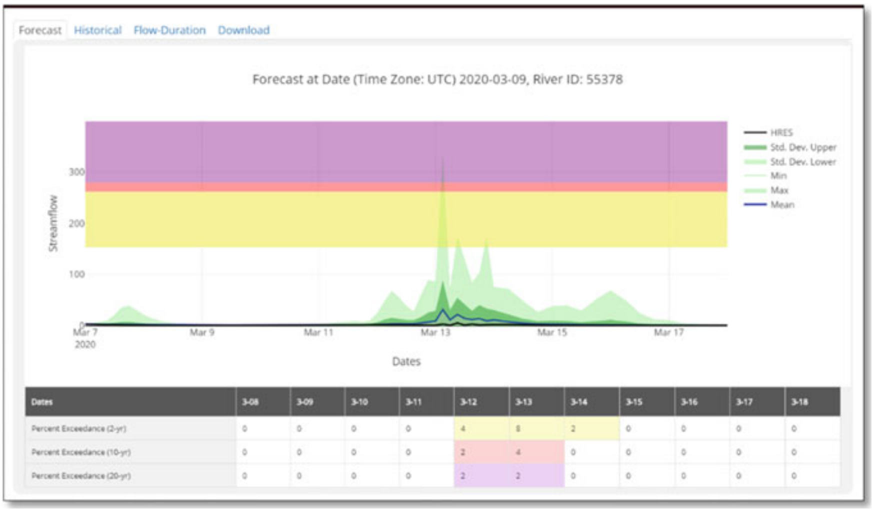

Fig. 9.6 Visualization of SPT forecasts and associated statistics, along with data on exceedance thresholds showing the probability of occurrence along a 10-day forecast range

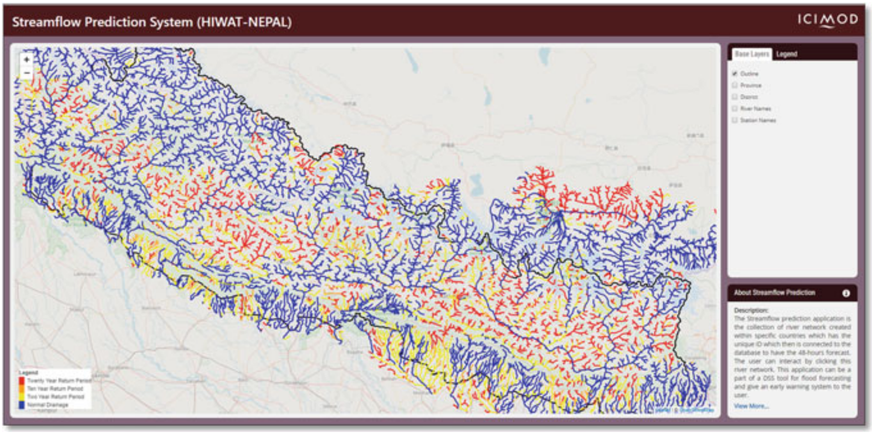

Fig. 9.7 HIWAT-based flood early warning system

first glance. During the co-development process with our partner, Nepal's Department of Hydrology and Meteorology (DHM), we also incorporated the river names, administrative boundaries, and the locations of the hydro-met stations into the system. The landing page for SPT-Nepal is given in Fig. 9.7.

Another successful integration has been the Bangladesh transboundary prediction system. This unique system is based on the 17 transboundary stations (points) provided by the Flood Forecasting and Warning Centre (FFWC) under the Bangladesh Water Development Board (BWDB). The system provides a 10-day forecast to their internal model which increases the warning/alert lead time within the country and hence saves lives and livelihoods.

Model consistency is achieved through the use of the same hydrological model and meteorological product to derive both streamflow forecasts and the reanalysis data set used to derive the thresholds. While it is difficult to accurately represent the true-flow conditions along a river network, early warning systems developed with exceedance thresholds derived from discharge simulation based on the reanalysis data lend greater meaning and provide a consistent, historical context to the model predictions.

9.5 Current State of Service Implementation and Validation

9.5.1 Dissemination and Delivery

In Bangladesh, the FFWC monitors water levels and provides deterministic forecasts of five days at 54 stations on 21 rivers. SERVIR's collaboration with the

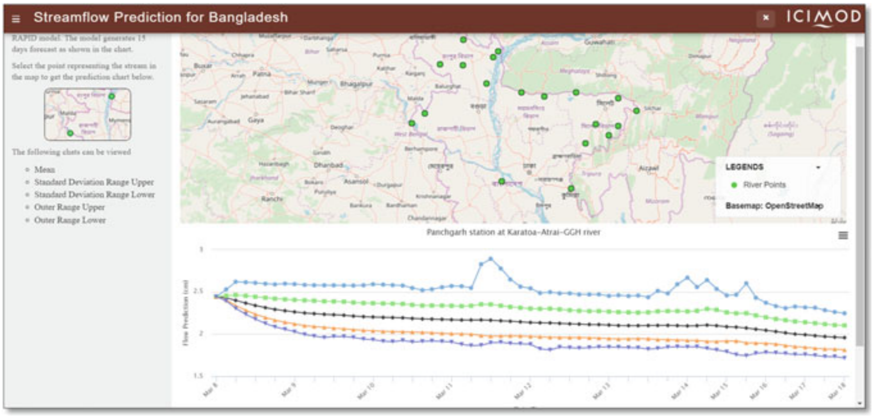

Fig. 9.8 Customized user interface for Bangladesh SPT web application at selected inflow stations of transboundary rivers

FFWC focused on four areas: warning on transboundary flow; flash-flood warning; flood-warning dissemination; and training and capacity development.

The FFWC forecast that is now operational was first generated using a MIKE11 Super Model, introduced in 1995–96 with a two-day lead time, and was later improved in 2012–14 to provide a five-day lead time. The model utilizes local precipitation levels and boundary flows at 17 locations across the northern boundary of Bangladesh to generate the forecast (Fig. 9.8). The data on catchment precipitation are received from the Bangladesh Meteorological Department (BMD). The boundary flows are provided through assumptions based on various regional models, including the GloFAS one.

To cite a particular instance, flash floods occurring in north-east Bangladesh, specifically in the wetlands of Haor, between April and May, pose a serious danger to crops and livelihoods. These floods are mainly caused by high-intensity rainfall in the neighboring catchment areas of India. Here, it has to be mentioned that effective forecasting of rainfall in the upper catchments is essential in capturing any potential flash-flood events which may miss the radar of the ECMWF's streamflow-prediction system. A HIWAT-based flash-flood warning system is also being developed for Bangladesh (Fig. 9.9), and it is now under the validation process. Besides, in 2018, a mobile app, integrated with the FFWC server and available for Android devices from Google Play store, was launched in Bangladesh for dissemination of flood warnings to the field-level staff and local communities. The app got a positive feedback in the monsoon periods of 2018 and 2019.

In Nepal, SERVIR-HKH is working closely with government agencies, particularly the DHM, in identifying test locations and evaluating the performance and usefulness of the service tools in adding value to the existing forecasting and early warning mechanisms. It is also partnering with service delivery and deployment organizations like Practical Action and Mercy Corps Nepal which are working

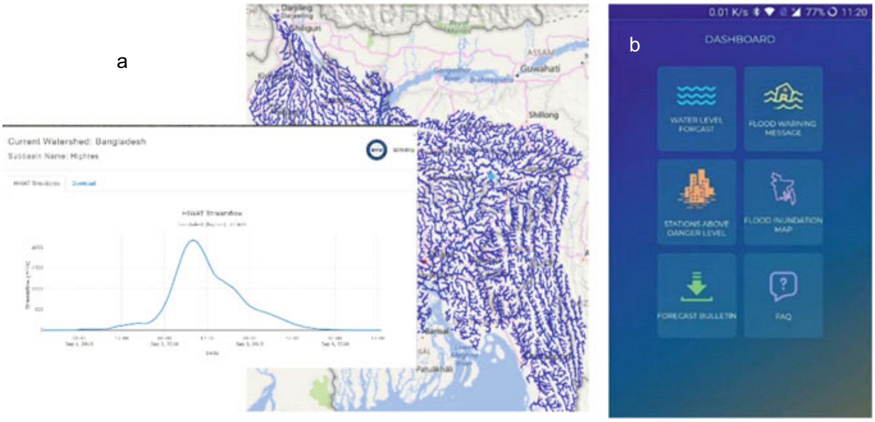

Fig. 9.9 **a** HIWAT-based flash-flood warning system for Bangladesh; and **b** mobile-app interface for early warning dissemination to the public

directly with the vulnerable communities and local administrations like the DEOC (District Emergency Operation Center) and the LEOCs (Local Emergency Operation Centers) in building capacities in flood preparedness and response. In Nepal, community-based partners are committed to augmenting new and existing community-based flood early warning schemes that have been widely adopted in flood-prone areas. The SERVIR-HKH project expects to use the information on the estimation of flood inundation to develop hazard maps in 10 watersheds spanning the Mahakali, Rapti, and Karnali basins. A network of flood warning systems has also been piloted by Mercy Corps Nepal in five watersheds of the Bagmati, Kandra, Kamala, Kankai, and Macheli using the HIWAT flash-flood prediction application. Such level of interest and engagement with a multitude of service intermediaries have led to a growth in the user base of SERVIR-HKH products and services. By increasing the lead time on warnings and by articulating forecasts in probabilistic terms, there has been a redefinition of approach in dealing with flood forecasts, and this has led to more effective preparedness and response procedures.

9.5.2 Capacity Development

Under SERVIR's capacity building program, equal attention has been paid to the professional development of the ICIMOD staff working in the SERVIR-HKH projects and to the partners in training them on the overall scientific basis, browser-based user interface, and access and interpretation of products and applications under different contexts of flood management. Following the training schedule, the group of IT personnel and programmers have acquired sufficient skills and competence to further improve on the modeling structure, implement enhanced visualization and system automation, and resolve issues that regularly come to their attention. The customized web applications on the Tethys platform continue to grow as new demands from the partners and users are being serviced. Now the streamflow-prediction model is slated to be run entirely from the in-house computing infrastructure. Besides, the control of the HIWAT run on the SCO-SOCRATES (SERVIR Coordination Office-SERVIR Operational Cluster Resource for Applications—Terabytes for Earth Science) cluster is being trialed for a phased handover. In all this, HIWAT's capabilities to enrich decision-making have been confirmed by several kinds of end-users (like the BMD and DHM).

The relevant staff of the FFWC in Bangladesh and other agencies with a stake in flood management have been trained on forecast validation to evaluate model performance and verify forecasts in order to understand the uncertainties and limitations in the forecasting models and to know about the ways in which they can be improved as reliable information for warnings. Later, a group of hydrological forecasters from Bangladesh, Bhutan, and Nepal, together with FEWS advocates and practitioners from community-based organizations, were put through a similar training program of in-depth exploration of the prediction tools and deployment in the operational mode. The participants were trained on using tools that create situational awareness and to apply products in a variety of decision-making contexts of water resources and flood management. Moreover, aspects of geoinformation technology in bringing processing and analytical focus on a specific area of interest were embedded perceptively into the practical sessions and hands-on exercises.

Skill and knowledge transfer through dedicated training runs have also been further strengthened through broadened participation in consultative workshops and knowledge fora. Hydrostats, a Tethys application, was extensively used for computing error metrics in the course of validating model forecasts and for assessing model skills in predicting an observed event. It is reasonable to state that the implementing partners and the key stakeholders have been provided with the knowledge and tools to interact, access the service products via the web interface or programmatically, and interpret and apply information to better manage water resources and reduce flood-disaster risks.

9.5.3 Validation

The forecast modeling tools have been calibrated and validated against several observed data sets collected from different locations around the world (Jackson 2018; Jackson et al. 2019; Snow et al. 2016; Swain et al. 2016a, b; Souffront-Alcantara et al. 2019; Nelson et al. 2019). Results from earlier validation efforts were optimistic that the modeled predictions were consistent with outputs from other systems using the same set of meteorological forcings and land-surface model (LSM) fields. Earlier validation works had also found out that the grid to vector adaptation did not alter the results, and showed good correspondence with the observed data from several locations around the world (Sikder et al. 2019). However, the studies were largely limited to either evaluating the ensemble mean forecasts against the simulated discharge climatology or comparing the latter with observations from selected stations.

A final round of forecast validation is being conducted focusing on predictions generated in real-time, which is archived on a daily basis to evaluate and investigate into the performance skills of the SERVIR-HKH flood-forecasting tools, i.e. HIWAT-driven flash-flood and ECMWF-IFS-based SPT tools. The approach extended the validation process to also assess the performance of ensemble forecasts in probabilistic terms using graphical measures like reliability, Talagrand, likelihood diagrams, and the Area Under the Receiver Operating Characteristics (AUROC). Brier score and skill score were used as numerical summary metrics to evaluate probabilistic forecasts in detecting flood days ahead of the actual occurrence. Besides, the forecast information primarily finds application in the development of flood early warning systems, which require an effective verification and validation method to understand the uncertainties and limitations that could be used in ways to improve the forecast and warning services. Accordingly, the forecasts were verified at each lead time with reference to observational records made available to the validation team by the partner agencies. Finally, the matching of the observed data sets were combined with modeled data sets for same time periods using a scheme of confusion tables to evaluate the tools' ability to correctly predict the dichotomous flooding events using binary scores, including, but not limited to, Probability of Detection (POD), Probability of False Detection (POFD), and Gilbert, Peirce, and Heidke skill scores. Forecasts were also evaluated against observations using a set for deterministic performance metrics using the mean of 51 ensemble members to assess temporal, bias, and spread vs skill errors. The forecast skills were demonstrated by benchmarking the forecast performance against climatology and persistence discharge upon which forecast runs were initialized on a daily basis. The validation period differed across the three countries depending on the observed time series of the discharge.

Altogether, SPT forecasts were validated against observations from 20 hydrological stations in Nepal, eight stations in Bangladesh, and 10 stations in Bhutan. Table 9.1 presents the summary scores and related statistics for a selected site from each country in order to illustrate the validation results, which are expressed as functions of prediction error and goodness of fit between modeled and observed data for the countries and stations provided with usable observational data from 1 January 2014 to the end of the observation dates. The validation exercise was performed specifically to check on the verified claims of quality, value, and reliability of the coupled ECMWF-RAPID flood-prediction model. The HIWAT-RAPID flash-flood prediction system has been evaluated and validated only at a few sites in Nepal and Bangladesh due to want of quality observations from the sites prone to flash flooding. HIWAT-based predictions present a unique challenge for validation, as the model outputs do not follow the normal hydrologic response of watersheds since the precipitation forecasts are directly translated into streamflow without adequately accounting for surface and groundwater processes.

Therefore, summary statistics and error metrics convey very limited meaningful information on the forecast performance. Graphical visuals are mainly used to validate the correspondence in timing and magnitude of flood peaks between forecasts and the observations; while qualitative verification is supplemented with categorical statistics computed from the elements of the contingency table.

The SPT-sourced predictions are an ensemble of 51 members to capture the level of uncertainty in the modeled forecasts based on the initial conditions of perturbation. The goal of validation is to assess the quality and value of SPT forecast products to accurately and reliably predict flooding events so that robust flood early warning systems are established. In order to demonstrate the full benefit of SPT, it is crucial that the service is assessed not only in the measurement space but also in the probability space to quantify uncertainties for better decision-making. Figure 9.10 shows the performance measure in probabilistic terms using reliability, talagrand, likelihood, sharpness, and ROC plots, assuming equal likelihood of each member in post-processing the ensemble timeseries to dichotomous flood events. For the purpose of this validation exercise, the 90th percentile of the observed discharge time series was selected as the threshold to distinguish between flood and non-flood situations over the period of evaluation. The exceedance probability was derived from the fraction of ensemble forecasts equaling or exceeding the threshold discharge. Brier score and Brier skill score (BSS) were computed for probabilistic forecasts as a composite score for reliability, resolution, and uncertainty. The probability forecast skill (BSS) of forecast performance is evaluated against initial state and climatology. Several other common metrics were also calculated in verifying the ensemble mean.

The average correspondence between individual forecasts and the events they predict as shown with ensemble error metrics suggests the acceptability quotient of the forecasts. Although there was generally a good linear relationship between what was observed and what was forecast (Pearson coefficient, R), the predictive ability of the model chains was consistently poor in the case of all the stations that were evaluated (in terms of NSE and KGE). While the GloFAS-RAPID system has a tendency to over-predict in mountainous areas (Bhutan), it generally under-predicts flood situations in the low-lying plain areas (Bangladesh), and the error terms and the level of bias are less than acceptable. However, overall, both the SPT and ECMWF-RAPID forecasting systems were able to capture the peaks and lows in the observed hydrographs as shown by the relatively high values of the Spectral Angle (SA) (Roberts et al. 2018) metric that compares the shape of the hydrograph time series over time. These results apparently point to the fact that the performance of the models, the ECMWF-RAPID combination in particular, could be improved further with the recalibration of the parameters of RAPID to more closely represent the local situation. Nonetheless, there was skill in the forecasting system compared to the reference persistence forecast based on using the last simulated or observed discharge, despite the fact that there was great uncertainty associated with the observed data sets shared by the collaborating national agencies. Although the coupled ECMWF-RAPID modeling system is able to predict streamflow with a

Table 9.1 Summary scores of SPT forecast performance and its evolution over a 15-day forecast horizon

Lead time															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gandaki, Nepal															
BS	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.12	0.06	0.06	0.06	0.06
BSSp	0.41	0.62	0.60	0.62	0.62	0.62	0.63	0.64	0.61	0.60	0.06	0.58	0.55	0.52	0.52
KGE	0.62	0.75	0.72	0.70	0.68	0.67	0.67	0.67	0.66	0.64	0.12	0.47	0.51	0.52	0.53
NSE	0.45	0.62	0.61	0.61	0.60	0.59	0.60	0.59	0.58	0.57	−0.11	0.55	0.56	0.54	0.54
Pbias	0.33	0.07	0.02	0.03	0.03	0.03	0.05	0.04	0.02	−0.01	0.68	0.16	0.03	−0.01	−0.05
R	0.82	0.80	0.79	0.78	0.77	0.77	0.77	0.77	0.76	0.76	0.60	0.76	0.77	0.75	0.76
RMSE	82.31	68.50	69.11	69.50	70.82	70.95	70.71	70.91	72.42	72.85	117.20	74.51	73.84	75.79	75.92
Sarighat, Bangladesh															
BS	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.08	0.08	0.08	0.08	0.08
BSSp	0.37	0.33	0.30	0.28	0.23	0.21	0.19	0.20	0.16	0.11	0.07	0.02	0.02	0.00	−0.01
KGE	0.31	0.23	0.24	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.38	0.31	0.31	0.31	0.31
NSE	0.40	0.31	0.29	0.32	0.30	0.31	0.33	0.36	0.36	0.35	0.32	0.26	0.26	0.24	0.23
Pbias	−0.31	−0.33	−0.33	−0.33	−0.34	−0.35	−0.36	−0.37	−0.38	−0.38	−0.36	−0.39	−0.40	−0.41	−0.41
R	0.77	0.75	0.74	0.74	0.72	0.70	0.70	0.70	0.70	0.68	0.66	0.63	0.62	0.60	0.59
RMSE	147.77	159.52	161.02	157.69	159.86	159.32	156.56	153.47	153.01	154.55	157.38	164.92	165.16	167.22	168.28
Wangdi, Bhutan															
BS	0.06	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08
BSSp	0.30	0.42	0.30	0.27	0.23	0.23	0.21	0.21	0.19	0.17	0.16	0.18	0.19	0.18	0.17
KGE	0.78	0.88	0.85	0.83	0.81	0.80	0.79	0.79	0.77	0.76	0.76	0.75	0.75	0.75	0.74
NSE	0.71	0.82	0.80	0.78	0.75	0.74	0.73	0.72	0.71	0.69	0.69	0.69	0.69	0.68	0.68
Pbias	0.16	−0.04	−0.09	−0.11	−0.12	−0.13	−0.13	−0.14	−0.15	−0.16	−0.16	−0.16	−0.17	−0.17	−0.17
R	0.88	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.85	0.85
RMSE	154.62	120.97	128.35	135.04	142.00	146.17	147.70	151.00	153.93	157.35	158.11	158.03	158.04	159.88	162.16

BS brier score; *BSSp* brier skill score wrt persistence; *KGE* Kling-Gupta efficiency (modified); *NSE* Nash-Sutcliffe efficiency; *Pbias* percent bias; *r* Pearson correlation coefficient; *RMSE* root mean square error

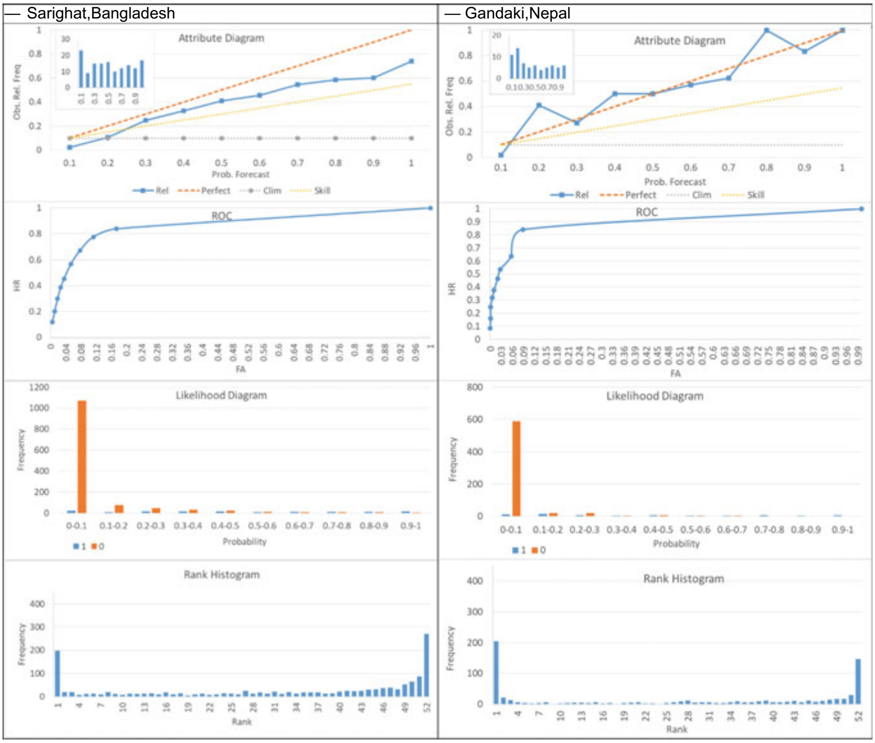

Fig. 9.10 Performance measure in probabilistic terms using reliability, Talagrand, likelihood, sharpness, and ROC plots for selected validation sites (one each from three countries as exemplar (Day-5 lead time)

15-day lead time, the forecasts are skillful only to a maximum of 10 days in the majority of the cases, after which the performance deteriorates rapidly.

Successful validation is expected to raise confidence in the forecast systems, and pave the way for the integration of the SERVIR-HKH system with the existing systems that have been operational for many years in Bangladesh and Nepal. The final integrated forecast will increase the lead time from the present two–three days to 10–15 days for river flow, and at least 40 h ahead of an extreme convection-driven flash flooding. The results from successful validation should promote the adoption of such tools as operational resource for the national hydromet services in order to improve accuracy and disseminate actionable warnings and alerts.

Small- to medium-sized basins in countries across the HKH region need such open and accessible service tools to downscale authoritative global forecast products to the level of localized ones that can create real impacts on the ground. Scaling the services up and out within the SERVIR-HKH focal countries and in the region can provide a common operating picture for countries to work and learn together in an atmosphere of shared responsibility when it comes to flood management. The prediction tools are in an advanced stage of joint evaluation under different basin scales—small, medium, and large—using river-flow observations obtained from the national partner agencies. Eventually, the service tools are pipelined for integration into respective national forecasting and warning systems so as to support decision-making and best practices in flood-risk management.

The validation process was designed around a tripartite engagement among NASA's AST, ICIMOD, and partners in Nepal and Bangladesh, and was later extended to include Bhutan. The actual validation was supported through the capacity building of partners on validation methodologies, data collection, and assemblage for target locations identified in consultation with the partners. The successful completion of the validation process will clear the products for use in operational settings.

9.5.4 Transition to Operational Service

The success in the adoption and use of flood-prediction services involves the engagement of multiple stakeholders who each have specific roles and responsibilities. A sense of ownership about the system that generates the services and adoption of the system by the local authorities responsible for disaster-emergency response operations at the district level and by the community workers at the local level are vital for sustained improvement and application. This entails continuous engagement with different levels of stakeholders.

9.5.4.1 Bangladesh

The FFWC is the mandated agency in Bangladesh to generate flood forecasts and provide early warning. The FFWC receives information on water levels from the automated stations installed by the BWDB; information on cross-border flow from the Joint River Commission (JRC); and on rainfall forecast from the BMD. These data are then used as input to a hydrodynamic model developed on a MIKE-II platform to generate water-level forecasts five days in advance. This forecast is disseminated through the FFWC website for consumption by the stakeholders, including the BWDB field operatives. With the introduction of the SERVIR streamflow prediction tool for boundary rivers, the FFWC is now initializing the model with inputs from the SPT. A mobile app has also been developed with support from SERVIR that enables wider dissemination (Fig. 9.11). And, to support the institutionalization of the process, ICIMOD and the BWDB have signed an MoU under which the FFWC officials are trained to use the system. Currently, the input from the SPT are manually ingested into the flood-forecasting model. In future, integration is planned to automatically synchronize the SPT with the flood-forecasting model to automatically ingest the boundary river flow.

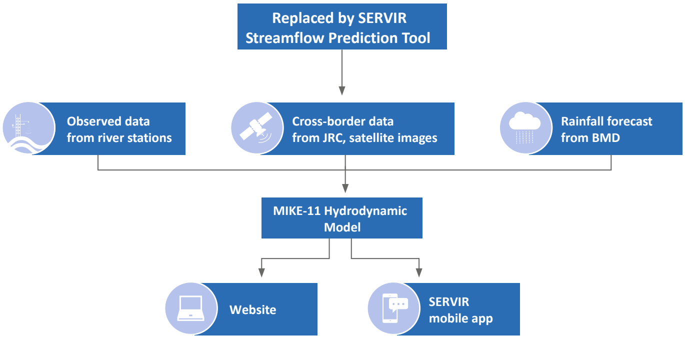

Fig. 9.11 Modified workflow in generating forecasts based on the boundary conditions derived from the SERVIR prediction models being implemented by the FFWC, Bangladesh

9.5.4.2 Nepal

In Nepal, the DHM is the primary partner in the SERVIR-HKH initiative in advancing real-time flood modeling as a service for enhancing EWS and to move the process towards formalizing the system at the national level. It is encouraging to note that from 2019 onwards, the DHM has started to include the forecasts from the SERVIR-HKH flood tools in the production and issuance of its regular flood outlook. The DHM is also currently extending all the necessary support into the joint validation of the real-time forecasts, and with renewed optimism to incorporate the products for complementary guidance, as well as to explore the prospect of future integration into its flood forecasting operations. Meanwhile, the other local partners under a similar collaborative arrangement, in particular Practical Action and Mercy Corps, working at the local level on flood-risk reduction, have reaffirmed their interest in testing the usefulness of the system at the local level. Besides, HIWAT-based flash flood prediction tools are being tested at the project sites of these local partners.

9.5.4.3 Bhutan

The National Center for Hydrology and Meteorology (NCHM) is an autonomous body of the Royal Government of Bhutan with the national mandate to establish, monitor, and inform the nation on the past, current, and future situations in weather, climate, and water-related matters of interest. However, despite Bhutan's modernization drive to improve its hydromet infrastructure, critical information on predicting the flooding conditions within relevant timescales continue to present a huge challenge in terms of the integration of decision-support tools and applications. The agency still lacks the necessary computing and trained professionals to develop and operate a modeling system to predict floods at both national and local scales. A 24-h hydrologic forecasting model-chain is being tested in one or two river basins using the meteorologic forcings from the WRF-based deterministic weather forecasts. Besides, the ECMWF-RAPID computational forecasting framework, coupled with the SPT web application on the Tethys platform, offers free access to vital flood information which can complement the local setup to provide situational awareness and outlook with quantified uncertainties. The HIWAT-RAPID modeling system is also set to be extended to predictions for smaller rivers which are naturally flashy because of severe convection-driven precipitation inputs.

Recognizing the benefits of these systems, the NCHM has decided to work closely with SERVIR-HKH in evaluating the system performance in major river basins in Bhutan. In the last one year, a group of hydromet engineers and forecasters from the NCHM participated in every capacity development event organized by ICIMOD. Recently, a combined product dissemination and model validation workshop was conducted in Bhutan to include the wider government stakeholders that are likely to benefit from the information products generated by the SERVIR-HKH tools. The event received good response from the government agencies responsible for river infrastructure, hydropower, and disaster-emergency management. Further, the NCHM has committed to strengthening collaboration in improving the systems by sharing resources, data, and experiences under a mutually agreed institutional mechanism. In the meantime, it has identified several gauging sites to validate the reliability and value of the systems in water-resource management and flood-risk reduction.

9.6 Learnings and Future Direction

9.6.1 Challenges and Opportunities

Flood frequency related thresholds that make use of recurrence intervals are found to misrepresent actual flood levels with serious implications for building trust in the system. The flow magnitudes of thresholding return periods do not always match with actual observation on the ground. The color-coded threshold envelops are misconstrued as warning levels, which, in fact, are still pending a reality check through systematic calibration with actual observations on the ground. In an ideal situation, these color bands should be associated with the magnitude of the likely impact from a flood event falling within a specific threshold band. Regardless, color-coded thresholding is unlikely to trigger response action without interpretive guidance or making sufficient efforts in raising awareness on what the colors signify.

ERA5 (Hersbach et al. 2018) is the latest climate reanalysis data set produced by ECMWF and distributed through the Copernicus Climate Change Service (C3S). ERA5 is superior to its predecessor, ERA-Interim, in that it incorporates more than 10 years of improvement in the numerical weather prediction system, higher spatial resolution, improved data assimilation, and near-real-time updates for the intermittent version, ERA5T. Using ERA5 data sets with the RAPID routing method in SPT could improve the discharge timeseries that is used in estimating flood thresholds based on frequency analysis for the return periods. In 2019, Alfeiri et al. indicated that setting discharge thresholds based on a ranged forecast horizon would be actually more informative while deploying SPT as an extension of flood early warning systems. Setting range-dependent thresholds, instead of time-invariant ones, has produced consistency along the entire forecast range, and is likely to improve the estimation of the magnitude of upcoming extreme events over longer forecast ranges.

The RAPID model, based on the traditional Muskingum formulation, routes only the surface run-off field from the ECMWF land-surface module along a vectorized river network, and does not account for the vertical water fluxes or the groundwater storage in the floodplains, or the interactions between surface and groundwater. The model can be improved further by replacing the simplistic Muskingum method with the numerical solution of the kinematic wave equation and incorporating routines for groundwater storage and transport. This enhancement to the routing process could reduce the overall model tendency to under-predict discharge in many river networks. And even if the Muskingum approach is maintained, there is ample scope to optimize its routing parameters to better represent the hydrologic characteristics of the HKH basins through a systematic calibration with the observed conditions. The other contributory features worth incorporating into a future scheme of enhancement could include simulation of transmission loss along channel reaches, and interaction with other components of river hydrology. With increasing human interference in the natural flow regime, it is also crucial that the model is capable of routing flow through channels modified by flow regulating and control structures causing backwater effects.

Flood prediction is not an end in itself; it must logically transit towards mapping the depth and extent of inundation to assess areas that are likely to be impacted to varying degrees of severity, in terms of potential costs and losses. Merely providing information on river discharge or water level will not induce appropriate response actions unless such information is translated into differential implications for lives and livelihood, asset, and infrastructure. To meet this requirement, the back-end modeling system of the prediction tools needs to be retrofitted with the capability of hydraulic simulation, or other means of implementing a flood-mapping system in an end-to-end flood early warning service chain. While the tools have inherent value in extending the lead time to actual hazard manifestation as events unfold, there are also weaknesses and limitations in any forecasting and warning services; these arise from the stochastic nature of the hydrometeorological process; for example, the non-linearity of flood hazards with no set pattern of expression. Moreover, the systems are not designed to be perceptive about societal exposures and vulnerabilities, nor do they account for the response capability in comprehending flood forecast and warning messages. Being web-based and without a localized and dedicated mobile version, the scope for widespread uptake is limited by the unequal access to the internet. Providing decision-support services online can be construed as discriminatory, favoring access by a capable few; whereas, the lower classes who are most at risk generally have no access to the internet. Thus, further customization is necessary to make the systems truly fit-for-purpose.

9.6.2 Way Forward

The scientific community in hydrological modeling is constantly developing improved methods of producing ensemble forecasts and data assimilation techniques to address the inherent uncertainty in the hydrologic modeling process. AI, machine learning, and data-mining techniques are increasingly being used for vulnerability assessment (e.g. analysis of satellite images to identify communities at risk) and also for risk calculation (Saravi et al. 2019). Through the advances and development in the last decade, these techniques have now been made available to even less developed countries through various collaborative platforms and assistance windows, thereby opening up a whole new avenue for operational FEWS.

As a result of the challenges posed by the complexity involved in inundation forecasting via predicted discharges, research efforts have expanded in recent years to seek out simplified approaches to inundation mapping, based on databases of simulated scenarios of flooding events by employing the similarity theory. However, there are major issues in recompiling the database as riverbed morphology changes over time, or significant changes occur in the land-use systems, such as the erection of artificial structures. Nonetheless, better flood-mitigation and flood-forecast planning strategies can be developed by visualizing the inundation scenarios of different magnitudes of floods and also by studying the various quantiles shown by discharge hydrographs.

As individuals are becoming more technology-bound than ever before due to smartphones, the internet, and the social media, all of these are being integrated into the warning dissemination systems by flood-forecasting centers and disaster managers worldwide. This will lead to more people acting as disseminators—communicating timely warnings widely via electronic and social media channels. Confidence and trust in FEWS are expected to increase as warnings are tailored to the needs of communities to enable them to make risk-informed decisions. Herein lies the relevance of impact-based forecasting and warning in bringing together providers and users on the same wavelength to connect the different components of early warning systems with specific focus on the sectors of interest.

9.7 Conclusion

The conventional ways of developing a hydrological modeling system for the purposes of flood forecasting and early warning present enormous challenges for countries that do not have the needed resources and technical capacity to develop, operationalize, and maintain such complex systems. The SERVIR approach of setting the modeling infrastructure in the cloud and facilitating hydro-informatics using open-source web technologies to deliver forecast results with visuals and statistical interpretation has systematically lowered those barriers in fulfilling the information needs about water in the HKH region. The approach has also addressed the communication challenges in disseminating forecast products and services that are comprehensible and usable under pressing decision contexts. The ECMWF-RAPID hydrologic modeling chain has addressed many application constraints identified in the GloFAS services used extensively by countries in the HKH region.

The streamflow-prediction system to which the web application tools serve as the intuitive and interactive user front-end has significantly enhanced the forecast capability in the HKH region by extending the forecast lead time to 15 days, and to a large extent, has quantified the uncertainties associated with deterministic forecasts. It has also reduced the processing latency in translating forecasts into early warning services by framing forecast results in the historical context of threshold exceedance in terms of the return periods. The intuitive interface and dynamic front-end processing and visualization system, with routines to access and retrieve outputs, are some of the benefits offered by the system, allowing the users to focus on the more critical and priority aspects of flood-emergency management to save lives and protect properties.

The HIWAT flash-flood prediction system is now appreciated by all national hydromet agencies within the region for its ability to forecast floods triggered by extreme precipitation events. The local convection-allowing physics configuration enables the meteorologic model to predict such events forcing the RAPID routing model. The services are especially crucial during the pre- and post-monsoon seasons when severe weather phenomena occur, and also in places dominated by conditions of poor surface infiltration and small watersheds. Flash flooding is a rare event, but the impact and consequences are far greater than those caused by seasonal riverine flooding. It is particularly important for communities settled around flashy stream beds and organizations engaged in actions of community well-being to have such reliable early warning service with sufficient lead time to plan and take action. While the system has only a 48 h forecast horizon, it provides far superior head-start than any instrument-based alternative. The outlook is promising, and SERVIR has brought cutting-edge technologies within the reach of research communities, government decision makers, emergency responders, and the general public of a region with global hydroclimatic significance.

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Chapter 10
Rapid Flood Mapping Using Multi-temporal SAR Images: An Example from Bangladesh

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10.1 Introduction

In the HKH region, large areas in Afghanistan, Bangladesh, China, India, Myanmar, Nepal, and Pakistan get inundated by floodwater during every rainy season. Among them, Bangladesh has been experiencing record-high floods where four types prevail: flash flood, local rainfall flood, monsoon river flood, and storm-surge flood; and these occur almost every year due to Bangladesh's unique geographical setting as the most downstream country in the HKH region (Ozaki 2016; FFWC 2020). On an average, about 26,000 km^2 of Bangladesh is inundated during the monsoon season (Fig. 10.1). Among all the disaster years, the floods of 1988 were the most catastrophic when more than 2379 people were killed, 45 million were affected, and 82,000 km^2 of land was inundated (Dewan 2015; Rasid and Pramanik 1993).

For the mitigation of flood disaster impacts, it is very critical to know which areas are inundated and which are not. Based on timely information on inundation, disaster and relief agencies can speed up emergency response for relief and rescue measures. At the same time, the flood-affected people can also find safe shelters (Manjusree et al. 2012; Uddin et al. 2013). Therefore, flood early warning, near real-time (NRT) inundation information and preparedness are the best options in flood disaster management (Uddin et al. 2019). Flood maps provide essential inputs toward assessing the progression of inundation area and the severity of the flood situation (Amarnath and Rajah 2016; Cigna and Xie 2020). Satellite-based Earth observation (EO) techniques are used for preparing such flood maps that help in assessing damages to residential property, infrastructure, and crops (Hill 2016; Uddin and Shrestha 2011).

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_10

Fig. 10.1 Inundation photo (August, 18 2017, Sirajganj) taken from an airplane; the gray water reflects the inundated areas, and the green patches are rural settlements covered by floodwater. Photo by Kabir Uddin

ICIMOD developed a rapid flood mapping method when Bangladesh was hit by floods in 2017 (Uddin et al. 2019). The flood maps were prepared for the months of March, April, June, and August and were provided to the disaster management agencies in order to prioritize relief and rescue operations. With some refinements, same method was used for mapping the floods of 2018 and 2019 in Bangladesh, Nepal's Terai, and the Koshi River Basin in order to support flood management and relief measures. This chapter explains the rapid flood mapping methodology developed for the 2019 floods in Bangladesh and its application.

10.2 Satellite Data in Flood Mapping

Though optical satellite imagery is most applicable for landform mapping, nevertheless, it is not appropriate for flood mapping due to the persistent cloud cover during the flood time (Uddin et al. 2019). As compared to optical data, microwave, i.e., SAR data are often used for flood area mapping. SAR is an active sensor that transmits a signal and receives the backscatter of the surface features using its own energy, unlike the optical sensor's dependency on the sun's electromagnetic energy. The SAR system operates on a long wavelength and can penetrate cloud, rain showers, and fog, making monitoring possible during flooding. Furthermore, the inundated areas often remain calm making the water surface smooth which results in less signal returned to the satellite. As a result, the inundated areas in the radar image appear darker in contrast to other land areas. These characteristics of SAR add significant values in terms of determining flood extent mapping and accurate measurement of streams, lakes, and wetlands (Ajmar et al. 2017; Amarnath and Rajah 2016; Ohki et al. 2016; Voormansik et al. 2014). Currently, satellites like ALOS-2, RADARSAT-2, TerraSAR, and Sentinel-1 are in operation and providing globally consistent SAR data. These satellites operate in different bands of microwave wavelength: ALOS-2 in L; RADARSAT-2 and Sentinel-1 in C; and TerraSAR in X. There are many flood mapping applications available from these satellites in the scientific literature, and it is suggested that compared to other bands, the L-band data provides the best results due to its longer wavelength and better penetration capability (Longépé et al. 2011; Shimada et al. 2014). However, ALOS-2, RADARSAT-2, and TerraSAR are operated on a commercial basis which involves procurement process that costs time and money. Therefore, Sentinel-1 SAR images are mostly preferred in flood mapping as it is available soon after the data acquisition, it is web-based open access and free for all and maintains relatively high-frequent observations.

So, for rapid flood mapping, we can take advantage of the Sentinel-1 data available in the public domain. The great asset of Sentinel-1 SAR images is that the data are freely available within a few hours of capture which helps to support NRT emergency responses.

10.3 SAR Data Processing Tools

There are many SAR data processing and analysis tools available in both open access—MapReady, Sentinel Application Platform (SNAP), Google Earth Engine (GEE), InSAR Scientific Computing Environment (ISCE), Generic InSAR Analysis Toolbox (GIAnt), Repeat Orbit Interferometry PACkage (ROI_PAC), Delft Institute of Earth Observation and Space Systems (DORIS), Generic Mapping Tools Synthetic Aperture Radar (GMTSAR), and PolSAR. In commercial modes—GlobalSAR, SARscape, Photomod Radar, SARPROZ, PCI, and GAMMA. The commonly used SAR processing tools on the open-access platform are MapReady, SNAP, GEE, and PolSAR Pro. These tools consist of proper documentation and can easily be handled by even non-expert flood analyst. In the commercial domain, the GAMMA software tool is widely used due to its availability on both desktops as well as cloud-computing platforms. The software is also popular among the SAR user communities for its capability inaccurate terrain correction. However, the cost factor of such commercial tools may be an issue with some users.

As for cloud-based data processing platforms like GEE, they provide excellent opportunity to process a large volume of satellite images at planetary scale at no monetary cost (Saah et al. 2020; Uddin et al. 2019; Kumar and Mutanga 2018;

Uddin et al. 2020). GEE maintains a data catalog and processing engine based on the programming languages, JavaScript and Python. The users can build the processing algorithm either in JavaScript or Python which directly access data from GEE's main repository or from its users' asset stored in the GEE cloud space and then apply the algorithm for processing the data.

10.4 Use of SAR Flood Mapping for Emergency Response in the HKH Region

In order to deploy rescue and relief operations, disaster management and humanitarian authorities need to know urgently about real-time flood situations. Nevertheless, the traditional flood mapping system has many limitations in terms of providing timely and updated information on the wider flood-prone landscape. In 2008, recognizing that flood maps are necessary for disaster preparedness, ICIMOD started its initiative of SAR image-based flood mapping (Uddin and Shrestha 2011). However, inundation mapping at the level of river basins was only initiated in 2016 when the Koshi River Basin, including India's most flood-prone state, Bihar, was hit by massive floods. So, in order to obtain reliable information on the Koshi River Basin, ICIMOD prepared a district-level flood inundation map for the Bihar State Disaster Management Authority (BSDMA). In this process, images from Advanced Land Observing Satellite - Phased Array L-band Synthetic Aperture Radar (ALOS-PALSAR) were used (Hill 2016; Bhubaneshwar 2016).

This map provided an estimate of the inundated areas, including of agricultural lands, grasslands, barren fields, built-up spaces, and fishponds. The map became useful for the BSDMA in its search-and-rescue operations and in managing relief camps (Bhubaneshwar 2016). However, due to their commercial nature, the data from ALOS-PALSAR were forbidding in terms of the expenses involved in mapping large areas and doing so every year. So, in 2017, for the first time in Bangladesh, rapid flood mapping via Sentinel-1 SAR was initiated which was then continued with when the country faced floods in 2019 (Fig. 10.3). The next section describes the methodology of mapping and the emergency response mechanism that were followed during the recent floods inundation in Bangladesh.

10.5 Rapid Flood Mapping—Bangladesh, 2019

For the mapping, 11 Sentinel-1 images were downloaded for Bangladesh directly from the Copernicus Open-Access Hub (https://scihub.copernicus.eu/dhus/#/home) as the data were available in a few hours from the time of acquisition. These images were in the interferometric-wide (IW) mode, with a minimum of 250-km ground swath in the C-band. The IW-mode data for the country were available as dual polarizations—vertical transmission and the horizontal received (VH) and vertical transmission and the vertical received (VV)—at level-1 of the ground range detected (GRD) products. Both polarizations were used in the mapping. Further, the Landsat-8 level-2 image that was acquired on September, 19, 2019 was downloaded from the US Geological Survey (USGS) Global Visualization Viewer (GLOVIS) and used for calibrating the algorithm and validating the flood map.

We used the Sentinel Application Platform (SNAP), an open-access tool available from the Copernicus Hub, for processing the SAR data. A graph builder was developed in SNAP to perform all the steps automatically in a batch-processing mode (Fig. 10.2). Firstly, the images were imported into SNAP. Then, they were radiometrically corrected by image calibration in order to represent the radar backscatter pixel values. After the corrections, the Lee Sigma, window size 7 × 7 speckle filter, was applied to reduce the granular noise that usually blurs features in images. Multi-look processing was also carried out to reduce the inherent speckled appearance and to improve the interpretability of the images. Further, terrain correction using the Shuttle Radar Topography Mission (SRTM) 30 m data was performed to remove geometric as well as topographic distortions in the images. The images were then converted from a linear scale to dB scale for true representation of the radar signals. Finally, a threshold for mapping the flooded areas was calibrated using the Landsat-8 data. For this analysis, only two major classes—water and non-water—were considered. The flooded area was determined by removing pre-flood waterbodies from the water extent during the flooding time (Jain et al.

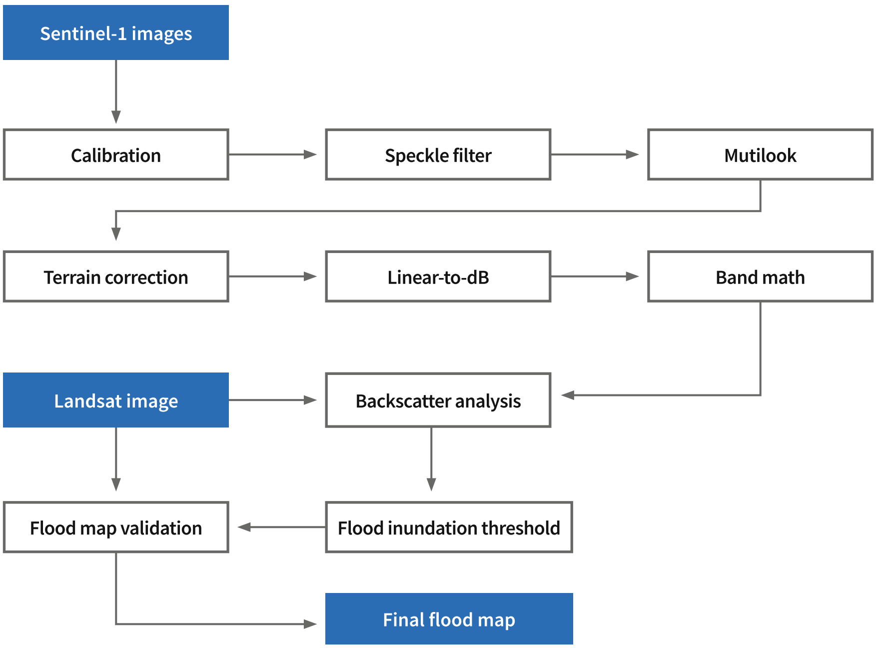


Fig. 10.2 Image processing flow

2006). The waterbodies that had water before mid-April were considered as perennial water bodies. The April 2019 waterbodies were separated from those of the months of June, July, August, and September, and the map was reclassified to indicate perennial waterbodies, flood areas, and other classes. To have confidence in the analyzed flood maps, we used 500 validation reference points from the Landsat image. The overall accuracy of the flood map in September 2019 as against the reference data was 98 percent. After that, an overlay analysis was carried out to trace the rise in flood and its recession between June and September 2019.

The inundation maps of multiple months were also analyzed for assessing the changes in flood situation during different times of the flooding period. An example of such analysis for the floods in 2017 revealed that while the total flood period spanned from April to August, there were some differences in the inundation patterns in different months. Some of the areas suffered from sustained flooding; in some others, the water had receded; while some areas were newly flooded. Comparatively, in the months of April and June in 2019, an area of 257,729 ha was inundated in both the months; an area of 38,776 ha had recovered from the inundation; and an area of 410,853 ha was newly flooded. At the same time, during the months of June and August in 2019, an area of 532,173 ha was flooded for both the months; some 136,406 ha had recovered from the floods; while an area of 502,927 ha was newly inundated. The 2019 rapid flood mapping exercise for entire Bangladesh went on to produce inundation maps for the months of June, July, August, and September (Fig. 10.3).

10.6 Dissemination and Outcome

One of the best outcomes of the flood mapping exercise was the rapid generation of inundation maps and sharing of that information with the relevant people using different communication channels. In addition to generating digital maps, the geo-referenced inundation data layers were also disseminated to a wider group of users through an information portal to enable further analysis by the users (WFP 2017). A web-based portal was also created for flood map visualization with overlay option showing different administrative boundaries. Such flood-associated information, maps, and data were downloadable to support further analysis by the users (Fig. 10.4). Digital maps of A1-size were also disseminated to disaster management committees for printing and using offline. The rapid inundation maps were widely used for responses and were appreciated by humanitarian agencies (Fig. 10.4).

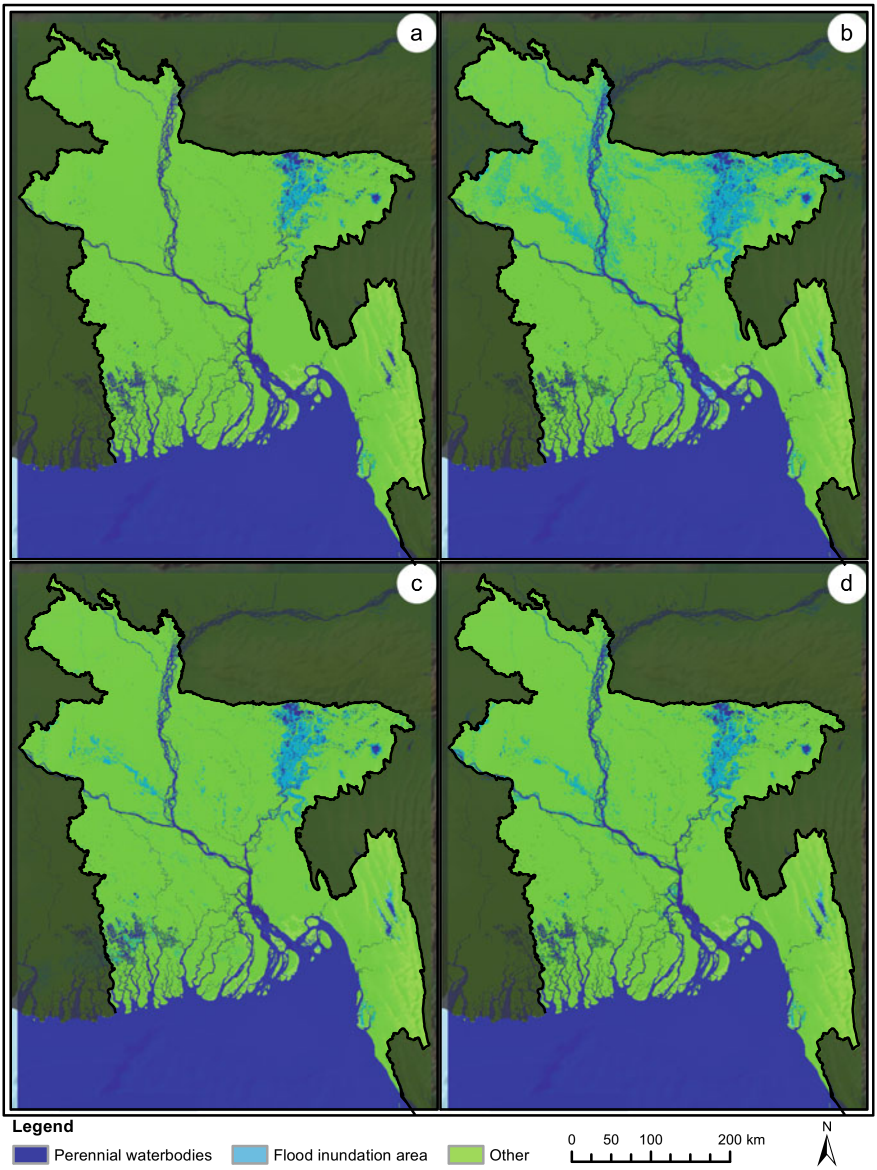
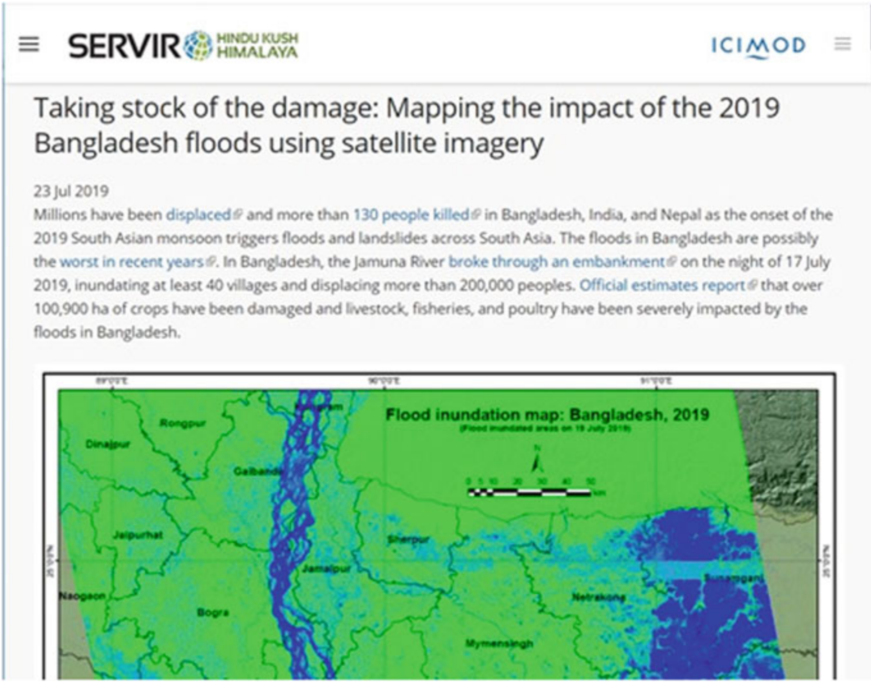


Fig. 10.3 Sentinel-1–based flood inundation map of Bangladesh for the months of: **a** June; **b** July; **c** August; and **d** September 2019


SERVIR HINDU KUSH HIMALAYA ICIMOD

Taking stock of the damage: Mapping the impact of the 2019 Bangladesh floods using satellite imagery

23 Jul 2019

Millions have been displaced and more than 130 people killed in Bangladesh, India, and Nepal as the onset of the 2019 South Asian monsoon triggers floods and landslides across South Asia. The floods in Bangladesh are possibly the worst in recent years. In Bangladesh, the Jamuna River broke through an embankment on the night of 17 July 2019, inundating at least 40 villages and displacing more than 200,000 peoples. Official estimates report that over 100,900 ha of crops have been damaged and livestock, fisheries, and poultry have been severely impacted by the floods in Bangladesh.

Fig. 10.4 News on flood mapping

10.7 Conclusion and Way Forward

This chapter has described the use of SAR satellite data and the open access software platform for flood mapping and has demonstrated a robust method to prepare NRT flood maps for rapid response missions. The application of the method for the Bangladesh floods of 2019 has been described as an example. The mapping method also achieved high classification accuracy. The flood maps show the high potential of EO and geospatial technology to analyze and provide the necessary support for prompt and effective decisions on flood disaster management to the authorities. In the wake of constant weather constraints during the flooding time, the example shows the rich potential of freely available Sentinel-1 SAR-based solutions to produce detailed mapping with high accuracy. The frequent occurrence of natural flood disasters is common in the HKH region, and it needs efficient tools for flood mapping in order to support damage assessment, emergency response, and disaster management.

However, desktop-based computer analysis limits the quick processing of large-scale mapping using Sentinel-1 images due to the file size. If all the Sentinel-1 data become available on an NRT basis in GEE, then the processing will be much faster to meet user needs during floods. The method can also be adapted easily in the earth engine platform. In the case of Bangladesh, the operational mapping applications have produced a flood map with the best precision at a national scale. Nevertheless, there were some issues with the flood maps due to existence of floating vegetation. The SAR Sentinel-1 images sometimes showed paddy fields as flooded areas while that was not the case. In those cases, local knowledge could play a significant role.

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Chapter 11
Monitoring of Glaciers and Glacial Lakes in Afghanistan

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11.1 Introduction

During the needs assessment in Afghanistan, the General Directorate of Water Resources (GDWR) of the National Water Affairs Regulation Authority (NWARA) (previously Water Resource Department (WRD) of the Ministry of Energy and Water (MEW)) emphasized that the compilation of comprehensive data on the glaciers in the country is a national priority.

Glaciers are of paramount importance in arid and semi-arid places like Afghanistan and serve as sources of freshwater for a large proportion of its population. Globally, the considerable evidence on retreat and shrinkage of glaciers, and the formation and expansion of glacial lakes have become a hot topic for researchers, scientists, and policymakers. The clear evidence of glacial retreat in Afghanistan, as found by ICIMOD's studies, poses a serious threat to the country's water security.

Worldwide, most glaciers have undergone major retreat since the end of the Little Ice Age (Marshall 2014; Zemp et al. 2014). This retreat was first noticed in the 1960s (Grotzbach 1964; Gilbert et al. 1969; Braslau 1972), and it accelerated in the last three decades (Gardent et al. 2014; Bajracharya et al. 2014a, b; Mernild et al. 2013). The HKH region has the highest concentration of snow and glaciers outside the polar regions and they play a pivotal role in supplying water to 10 major river basins (Bajracharya and Shrestha 2011). Glacial changes are also a valuable indicator of climate change (Wester et al. 2019; Nie et al. 2017; Song et al. 2017; Bajracharya et al. 2014a). By the end of the twenty-first century, the global surface

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_11

temperature is likely to exceed by 1.5 °C (IPCC 2013). In the case of Afghanistan, the reanalysis data from the period 1951 to 2010 show that the mean annual temperature increased in all parts of the country by 1.8 °C, with the highest increase of 2.4 °C recorded in the south, 1.6 and 1.7 °C in north and central part of the country, and 1 °C in the Hindu Kush Region (Aich et al. 2017). It is also observed that the warming in the main glaciated region of Afghanistan (Badakhshan) is between 0.3 and 0.7 °C. Moreover, the projection of mean temperature under RCP 4.5 indicates that by the 2050s, the strongest warming in the country is set to take place in the Wakhan Corridor—by over 2 °C—followed by the Central Highlands—by 1.75 to 2 °C (Aich et al. 2017). This rise in temperature will obviously lead to the melting of glaciers, trigger variability in snow cover, and change the other components of the cryosphere. Further, the combination of dust storms—mainly originating from the Central Asian countries and the northern deserts of Afghanistan—and the aerosols resulting from anthropogenic activities complicate the interaction between the atmosphere and the dynamics of the glaciers (Prasad et al. 2011).

It is all too well known that changes in glaciers will have a significant impact on the water resources—it will reduce water availability and the hydropower potential and change the seasonality of flows in the region. Glacier retreats often lead to formation of glacial lakes, the expansion of existing glacial lakes, and to Glacial Lake Outburst Floods (GLOFs). In this regard, several catastrophic GLOFs have already been reported from the region (Gurung et al. 2017; Allen et al. 2015; Bajracharya et al. 2007). A recent GLOF in a tributary of Panjshir River (on 12 July 2018) not only devastated the village of Peshghor in Khenj but also dammed the Panjshir River, thereby inundating the main river valley for up to 1.7 km from the river confluence. This GLOF was due to the sudden release of glacial lake water from newly developed and rapidly expanded glacial lake on the surface of the glacier ice covered by debris due to melting of glacier ice and snow. The glacial lake water released through the sub-glacial channel due to melting and erosion of underneath ice and debris (Maharjan 2018; Afghanistan Times 2018; Flood List 2018). The flood took place at midnight, thereby trapping the people who were asleep. Ten people lost their lives, while there were severe damages to livestock and property—some 300 houses were swept away, over 20 villages were affected, and a market in the Peshghor area also bore the brunt (Afghanistan Times 2018). It is in such a context that the monitoring of glaciers and glacial lakes in Afghanistan gains critical importance; in-depth studies must be conducted to understand the response of glaciers to climate change and on how climate change affects the overall hydrology of the country.

In Afghanistan, glaciers serve as the headwaters of the Panj-Amu (Amu Darya) River Basin and the Kabul River Basin which contribute to the Indus river basin. However, there is very little information on the country's glacier extent and on periodic glacial changes because of the complex topography, paucity of field work, and geopolitical restrictions. This means there is not enough understanding about freshwater availability, potential glacial hazards, and future scenarios on water availability in Afghanistan. As regards addressing the gaps in information on the periodic changes in glaciers and glacial lakes, since 2017, ICIMOD has been working closely with the GDWR to develop the capacity of Afghan professionals in this area and to prepare detailed information on the status and changes in glaciers and glacial lakes. This collaborative research has helped to comprehend the recent (2015) and decadal (1990, 2000, and 2010) scenario of glaciers and glacial lakes; it has also generated a four-period database that would shed more light on glacial melt and glacial hazards, and thus predict the future scenario of water availability in the country.

11.2 Glacier and Glacial Lake Monitoring Approach

Glaciers and glacial lakes are interwoven components of the cryosphere. Glaciers are composed of snow, ice, water, and rock/debris which move slowly down the gradient and melt due to changes in temperature. Glacial lakes are formed by the impoundment of meltwater in the lowlands formed by glacier erosion and/or blocked by the glacier-deposited moraine.

In general practice, the mapping and monitoring of glaciers and glacial lakes are done either through field practices or through remote sensing. Field-based monitoring is widely practiced to gauge glacier mass changes. It also helps in gathering information about the physical characteristics of a glacial lake, its moraine dam, and other surrounding features so that the risk of GLOF is mitigated. The demarcation of the boundary of a glacier and glacial lake is conducted using various survey instruments like total stations and the differential Global Positioning System (dGPS) in the field. Although the field-based method provides more accurate information, it is only applicable in the case of a few accessible glaciers; the rest is almost inaccessible due to rugged terrain and extreme weather conditions; there's also the factor of time and resources.

Before the availability of satellite images, glaciers were mostly studied via fieldwork. A few scientists have conducted field-based studies on some of the Afghan glaciers; this was before the 1980s. In 1964, Grotzbach noted a general glacier retreat in the Khwaja Mohammed mountains; in 1969, Gilbert et al. studied a small glacier near Mir Samir in central Hindu Kush; (in 1972, Braslau) studied the general recession of the Keshnikhan glacier at the entrance to the Wakhan Corridor; in 1976, Breckle and Frey (1976a, b) noticed relatively strong glaciation in east and south-east Afghanistan near the Pakistan border; in 1974, Austrian investigators (Patzelt 1978) measured the glacier orientation, maximum and minimum elevation, length, total area and debris-covered area, glacier hypsometry, and glacier changes in the South Issik glacier; Patzelt also studied the transient snow lines, the lateral moraine altitude, and the daily ablation rates of the glacier (Haritashya et al. 2009).

In the past, field and aerial photographs were widely used to study glacial changes. The Russians were very much interested in the glaciers of Afghanistan because of the meltwater resources that flow out of the country, towards the north. They conducted an intensive study in some parts of the Wakhan area (Haritashya et al. 2009). They carried out stereo-aerial photography covering one-third of the northern part of Afghanistan (Shroder 1980, 1989). In 1974, they began to prepare a glacier inventory of Afghanistan using incomplete sets of small-scale topographic maps derived from the aerial photographs taken in 1958–1959.

The recent development in RS and GIS techniques offer great potential for mapping and monitoring glaciers and glacier lakes on a larger scale and in shorter time periods (Paul et al. 2002; Bhambri and Bolch 2009; Bolch et al. 2010). These techniques enable automated image analysis, thereby reducing the time and cost to analyze the changes during various time periods. They also allow for geodetic surveys of individual and the entire river basin system.

In 2014, a team from Global Land Ice Measurements from Space (GLIMS) published a book on glacier studies at the global scale, which also carries a separate chapter on the study of glaciers using remote sensing in Afghanistan and Pakistan. This study, using various satellite images, reported the retreat of glaciers in Afghanistan, but could not come up with a digital data set of glacial changes for the whole of Afghanistan. In 2011, ICIMOD published a report on the status of glaciers in the HKH region, which also covers the glaciers in Afghanistan. However, the report does not cover the glacial area changes in Afghanistan; it provides only one-time data. Hence, the present study was initiated to prepare a database on the changes in glacier and glacier lakes in Afghanistan; this database is based on RS and GIS tools and techniques.

11.3 Implementation

The study adopted a semi-automatic method using an object-based image classification (OBIC) (Bajracharya and Shrestha 2011; Bajracharya et al. 2014a, 2018), to prepare the clean-ice (CI) and debris-covered (DC) glacier as a separate entity. For consistency, the same approach of mapping was applied for glacial lakes with

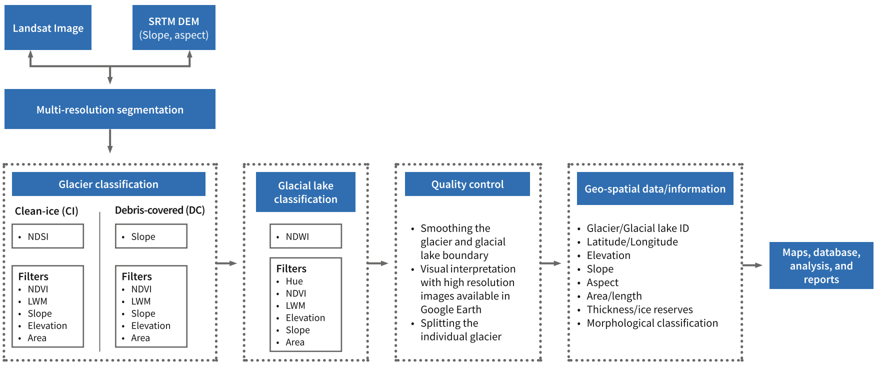

Fig. 11.1 Detailed methodology of mapping glaciers and glacial lakes

the images used for glacier mapping (Fig. 11.1). The overall process of mapping consisted of separate algorithms for CI and DC glaciers as also for glacial lakes but with some manual intervention. The detailed multistage process of mapping glaciers and glacial lakes is summarized in Fig. 11.1.

The study used a series of Landsat (TM, ETM+ , and OLI) images which are freely accessible and have a long historical record from 1980s. However, throughout the study area, due to topographic and climatic variability, it was difficult to get ideal images without cloud cover and least snow cover during the same time period. So, the images were selected with a one-year buffer of the representative year—for example, Landsat images from 2014 to 2016 were considered for mapping to represent the year 2015.

The classification of multispectral images, combined with the digital elevation model (DEM), was processed in the eCognition software. At first, the Landsat images of 2015 were used to prepare the status of glaciers and glacial lakes of Afghanistan. In this process, the image was segmented using multi-resolution segmentation mechanism which creates the image objects based upon spectral reflectance, shape, texture, and the relation to neighboring objects. These image objects were then classified based on spectral and spatial characteristics. Separate algorithms were used for mapping CI and DC glaciers and for glacial lakes. The CI part of the glaciers was mapped using the Normalized Difference Snow Index (NDSI); however, here it has to be noted that the threshold value of NDSI also captures the snow cover and other features such as shadows and waterbodies. These misclassified features were then eliminated by using various filters. Similarly, the DC part of the glaciers was mapped using the slope from the remaining unclassified objects, and various filters were used to eliminate the misclassified features (Fig. 11.1). For glacial lakes, the Normalized Difference Water Index (NDWI) was used to map the lake boundary. Sometimes, ice cliffs and walls of supra-glacial lakes are misclassified as glacial lakes, which were corrected by using various filters like Hue, Normalized Difference Vegetative Index (NDVI), and Land and Water Mask (LWM) (Fig. 11.1). The final output of the image classification was exported as vector data sets. The minor visual corrections, as well as quality checks and generation of parameters for the glaciers and glacial lakes, were conducted in the GIS environment. The other time data sets from the years 1990, 2000, and 2010 were generated by manually editing the 2015 data overlaying on the respective images of those three years. For higher accuracy and data quality, the results were further refined manually by backdropping the respective Landsat images and cross-checking on the available high-resolution images in Google Earth.

Table 11.1 Distribution of glaciers in each sub-basin of Afghanistan in 2015

Basin	Sub-basin		Number		Area (km^2)			Largest area (km^2)	Estimated ice reserve (km^3)	Elevation (masl)				Mean slope (deg.)	
	Name	Area (km^2)								Min.		Max.			
			CI	DC	CI	DC	Total			CI	DC	CI	DC	CI	DC
Panj-Amu	Upper Panj	17,196	1897	132	1555.02	87.23	1642.25	39.36	114.199	3452	3201	7175	5298	26	11
	Lower Panj	11,611	378	13	194.03	3.06	197.09	4.94	8.922	3524	3698	5182	4216	22	11
	Kokcha	22,196	988	134	428.42	64.50	492.92	10.67	22.955	4167	3608	6783	5406	27	12
	Taluqan	10,888	253	25	84.76	8.09	92.85	5.77	3.917	3995	3668	5746	4986	28	15
	Upper Kunduz	16,524	62	7	11.17	1.80	12.97	1.33	0.355	3877	3783	5050	4602	25	13
	Total	90,716*	3578	311	2273.40	164.67	2438.07	39.36	150.348	3452	3201	7175	5406	27	13
Kabul	Kunar	11,009	206	25	75.85	10.88	86.74	9.38	4.270	4132	3924	6147	5373	25	14
	Laghman	6224	38	4	4.57	1.06	5.63	1.24	0.145	4246	4389	5216	4658	31	10
	Upper Panjshir	3756	68	4	10.19	1.19	12.09	2.40	0.382	3912	4223	5254	4562	27	10
	Ghorband	4640	1	0	0.07	0.00	0.07	0.07	0.001	4253		4382		27	
	Total	71,266*	313	33	90.68	13.87	104.53	9.38	4.798	3912	3924	6147	5373	28	11
Total		~650,000#	3891	344	2364.08	178.55	2542.60	39.36	155.146	3452	3201	7175	5406	27	12

Note *Represents the total area covered by basins, #the total area of the country

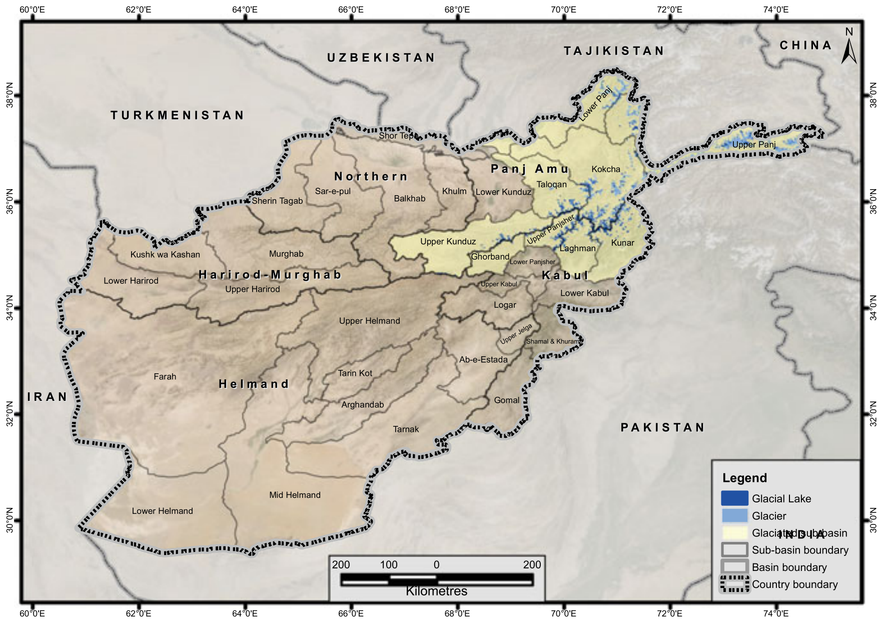

Fig. 11.2 Distribution of glaciers and glacial lakes in Afghanistan

11.4 Results

11.4.1 Status of Glaciers and Its Changes

Based on the Landsat images of 2015, altogether, 3891 glaciers were mapped, spanning an area of 2543 km^2 (Table 11.1). The table shows that the glacial area covers about 0.4% of the total land area. Among the five river basins in Afghanistan, two major river basins—Panj-Amu and Kabul—consist of glaciers; while Panj-Amu accounts for 92% of the glacier area, the Kabul basin accounts for the rest 8% (Fig. 11.2). The Upper Panj sub-basin of the Panj-Amu River Basin consists of the highest concentration of glaciers, which is almost 65% of the total glacial area in the country. The largest glacier, with an area of 39.36 km^2, also lies in the Upper Panj sub-basin at the narrowest part of the entrance to the Wakhan Corridor. The glaciers are distributed along elevations of 3200–7175 masl. The highest and lowest glaciers are in the Upper Panj sub-basin. And the highest concentration of glacial area is at 4500–5500 masl, covering about 78% of the total glacial area.

Most of the glaciers are mountain or valley glaciers of cirque or simple basin morphological type. Some larger valley glaciers are of the compound basin types. CI and DC are the two main parts of a basin glacier, be it mountain or valley glacier. Almost 9% of the glaciers in the country have the debris-covered part,

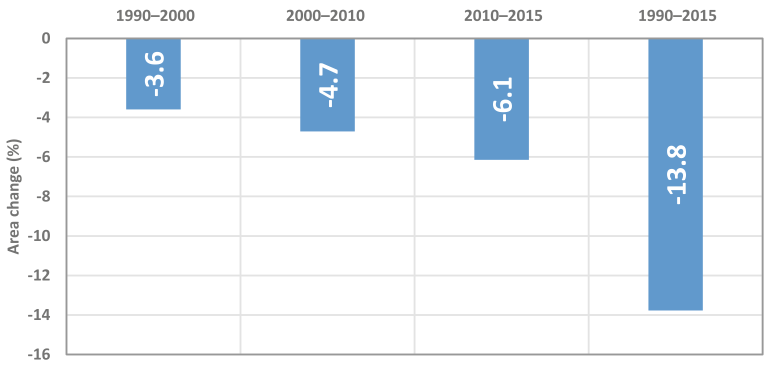

Fig. 11.3 Percentage of glacial area changes in Afghanistan

accounting for almost 7% of the total glacial area in the country. The number and area-wise distribution of the DC glaciers are higher in the Upper Panj and Kokcha sub-basins of the Panj-Amu River Basin. The average slope and elevation distribution of the DC part is lower than the CI part of glaciers.

The glacier change database of the years 1990, 2000, 2010, and 2015 shows that 13.8% of the glacial area was lost within this 25-year period (Fig. 11.3). The rate of area loss was 3.6% between 1990 and 2000; 4.7% between 2000 and 2010; and 2–7% from 1990 to 2000. But this rate increased to 4–12% from 2000 to 2010 in most of the sub-basins. The area loss was about 6.1% in the five years from 2010 to 2015. This indicates that the area-loss percentage has been higher in recent decades.

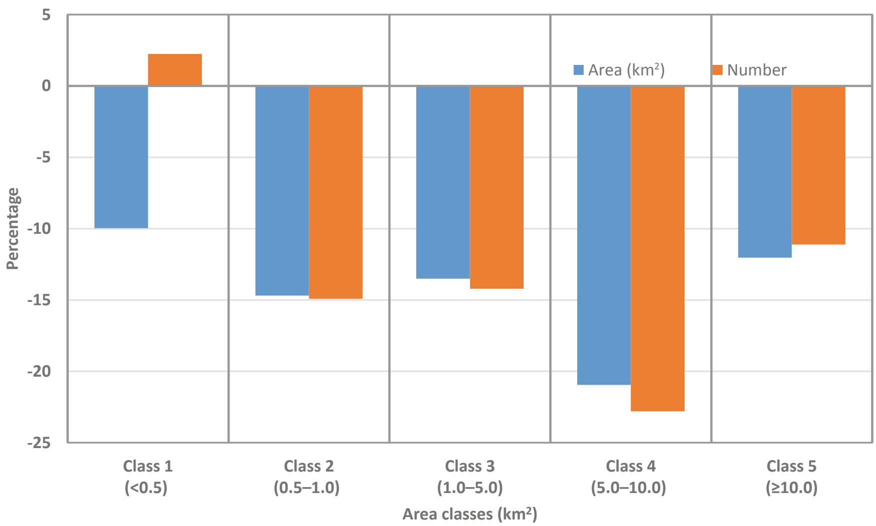

Fig. 11.4 Number and change percentage in each area size class from 1990 to 2015

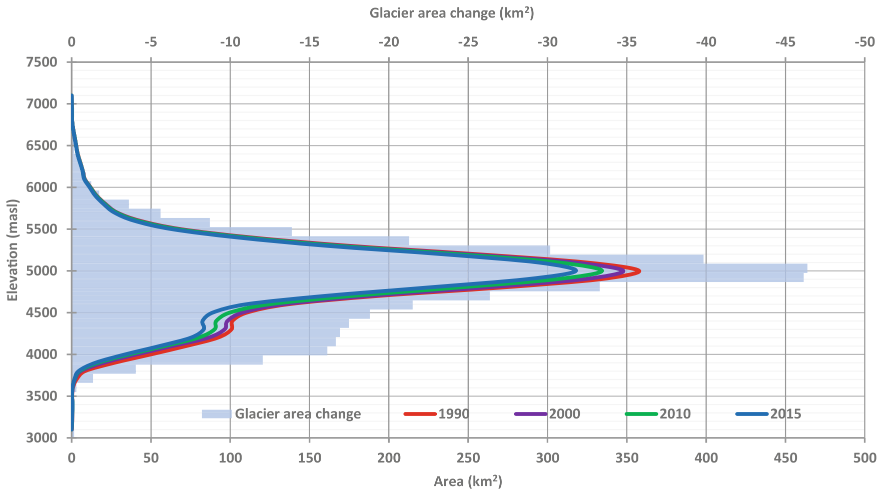

Fig. 11.5 Distribution of glacial area and changes in area from 1990 to 2015 at 100 m elevation zone

The study covered all the glaciers of sizes greater than or equal to 0.02 km^2. The glacial area size distribution of five classes is shown in Fig. 11.4, which demonstrates that the number of glaciers has decreased in 25 years except in the case of smaller ones. The area of the glaciers has also decreased in all size classes, with a higher percentage of decline among the larger ones. This indicates that the glaciers in Afghanistan are shrinking and retreating at a quick rate. And due to the shrinkage and fragmentation of the larger glaciers, the number of smaller ones has increased. At the same time, the smaller glaciers have also shrunk, with some of them shrinking to an area less than the threshold of 0.02 km^2; besides, some of the smaller glaciers have disappeared altogether, leading to a reduction in the number of glaciers in Afghanistan.

In Fig. 11.5, the area-wise distribution of glaciers shows the variations in area loss at different elevations. The maximum area loss was at elevations from 4700 to 5200 masl. In 25 years, the largest glacial area loss was 47 km^2 at elevations from 4900 to 5000. There have been no significant changes in the glacial areas above 5500 masl, whereas the glacial areas below 3200 masl have completely disappeared.

11.4.2 *Status of Glacial Lake and Its Changes*

Based on Landsat images, the current study mapped the glacial lakes of sizes greater than or equal to 0.003 km^2. This study covered all the waterbodies that are situated proximal to present glaciers as well as those located in lowland areas that were formed by paleo-glaciation (Maharjan et al. 2018). These lakes were analyzed based on size, altitude, and morphological classification using the available SRTM DEM (Shuttle Radar Topography Mission—Digital Elevation Model) and high-resolution images from Google Earth. These lakes were classified into seven types based on their damming condition and morphological location: (a) moraine dammed—end moraine (M(e)), lateral moraine (M(l)), and other moraine dammed (M(o)); (b) ice-dammed—supra-glacial (I(s)) and dammed by valley glacier (I(v)); (c) bedrock dammed—cirque (B(c)) and other glacier erosional (B(o)); and (d) other dammed lakes (O)—dammed by landslides, debris flow, etc. lying on glaciated valleys and fed by glaciers.

In total, 1942 glacial lakes, covering an area of almost 89 km^2, were mapped via the Landsat images of 2015. The lakes are distributed within the two major river basins of the country—Panj Amu and Kabul. The Panj-Amu basin has the largest number of glacier lakes, around 64% of such lakes in the country, covering almost 74% of the total area covered by glacial lakes in Afghanistan (Table 11.2). The size of the lakes ranges from 0.003 to 14.63 km^2, with a mean size of 0.5 km^2. The majority of the lakes are smaller than 0.5 km^2; only 10 lakes are larger than 0.5 km^2 and most of these either other dammed or bedrock dammed lakes except two lakes are moraine dammed (Fig. 11.6). The smallest lakes (of size less than 0.02 km^2) account for 52% (number = 1009) of the total lakes in the country. More than 71% of the lakes are bedrock-dammed ones which are mostly formed on the erosional

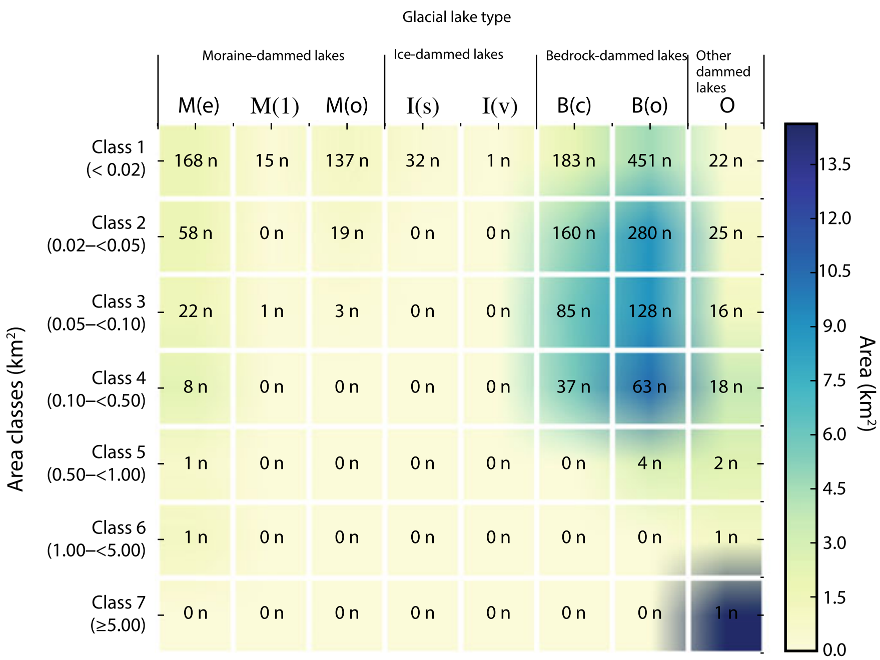

Fig. 11.6 Number and area-wise distribution at different size classes and types of glacial lakes

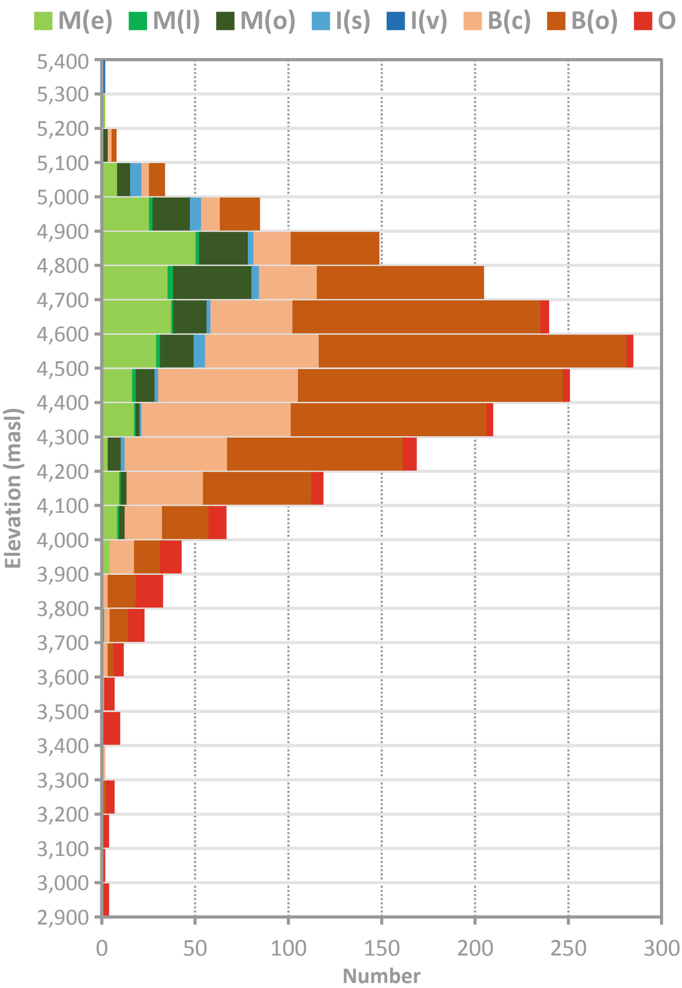

Fig. 11.7 Glacial lake distribution at 100 m elevation zone

surface of glaciers. The remaining 22.5% are moraine dammed and most of these (almost 17%) are smaller (less than 0.02 km^2) in size, and have an average size of 0.025 km^2.

The altitudinal distribution of the glacial lakes ranges between 2900 and 5400 masl, with the largest number of lakes (83% of the total) situated within an elevation range of 4100–4900 masl (Fig. 11.7).

So, considering the formation of new lakes, the expansion of lakes, and even their disappearance, going by the data of the years 1990, 2000, 2010, and 2015, it emerges that the development and evolution of glacial lakes have been inconsistent. Overall, the change database shows increase in the number and area of the glacial

Table 11.2 Distribution of glacial lakes in Afghanistan (2015)

Gl type		Panj-Amu				Kabul				Afghanistan			
		Number		Area		Number		Area		Number		Area	
		Count	%	km^2	%	Count	%	km^2	%	Count	%	km^2	%
Moraine dammed (M)	End-moraine-dammed lakes—M(e)	229	18.4	8.138	12.5	29	4.2	0.575	2.5	258	13.3	8.713	9.8
	Lateral moraine-dammed lakes—M(l)	15	1.2	0.232	0.4	1	0.1	0.01	0.0	16	0.8	0.242	0.3
	Other moraine-dammed lakes—M(o)	143	11.5	1.716	2.6	16	2.3	0.198	0.9	159	8.2	1.914	2.2
Ice dammed (I)	Supra-glacial lakes—I(s)	27	2.2	0.201	0.3	5	0.7	0.035	0.2	32	1.7	0.236	0.3
	Other ice-dammed lakes—I(v)	1	0.1	0.007	0.0	0	0.0	0	0.0	1	0.1	0.007	0.0
Bedrock dammed (B)	Cirque lakes—B(c)	216	17.4	9.119	14.0	249	35.6	9.608	41.0	465	23.9	18.727	21.1
	Other bedrock-dammed lakes—B(o)	538	43.3	23.893	36.5	388	55.5	12.036	51.4	926	47.7	35.929	40.5
Other dammed—O		74	6.0	22.078	33.8	11	1.6	0.952	4.1	85	4.4	23.03	25.9
Total		1243	100.0	65.384	100.0	699	100.0	23.414	100.0	1942	100.0	88.798	100.0
Percent		64		74		36		26		100		100	

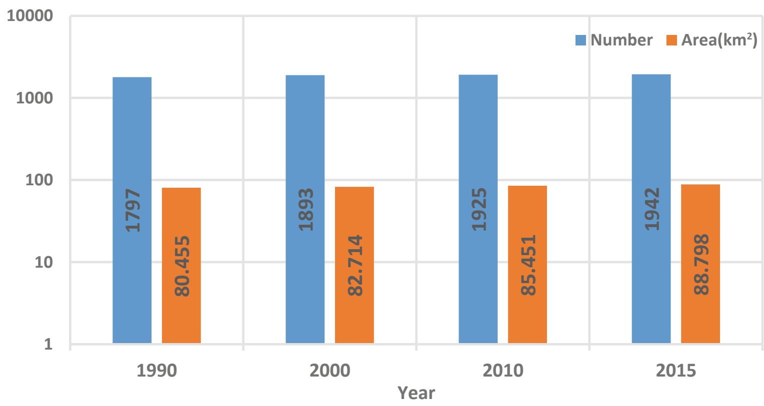

Fig. 11.8 Number and area of glacial lakes in four time periods from 1990 to 2015 in Afghanistan

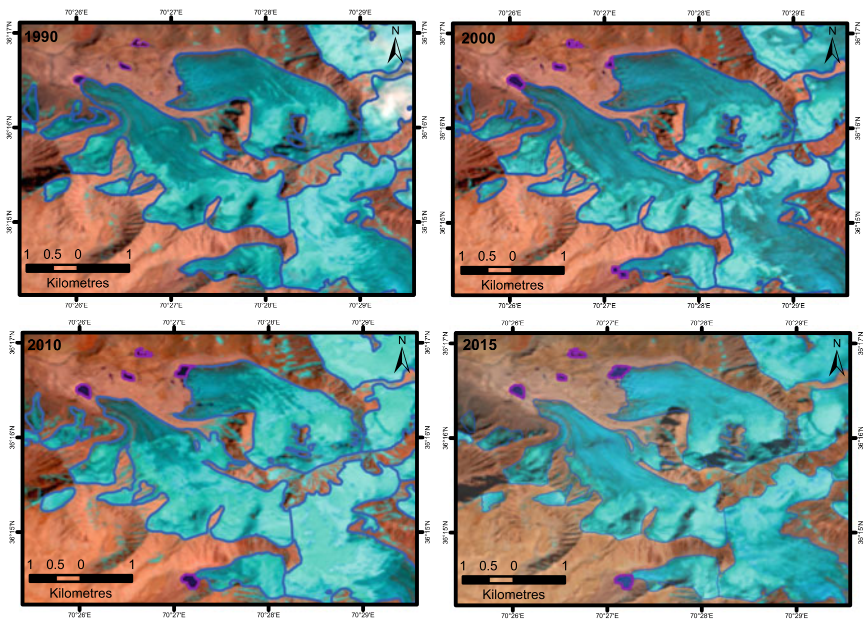

Fig. 11.9 The formation and expansion of glacial lakes; an example from the Taloqan sub-basin of the Panj-Amu River Basin

lakes. In the 25-year period, the number has increased by 8% and the area by 10% (Fig. 11.8). The changes are inconsistent, as they depend on the type of lake and the elevation range. It's mostly the moraine dammed lakes that are in contact with glaciers which have expanded (Fig. 11.9). The expansion of these lakes is mostly towards the direction of glaciers, in the space left by the glacier retreat. New lakes were formed due to shrinking and melting of glaciers, which is indicated by the increase in the number of lakes of smaller size (less than 0.05 km^2). And the comparatively higher rate of expansion took place among lakes with an area of 0.5–0.5 km^2. The number of moraine-dammed lakes increased in both decades 1990–2000 and 2000–2010, whereas the number of bedrock-dammed lakes and other lake types showed a decline. Mostly, the changes in lake size and the formation of new lakes are evident in the 4000–5100 masl elevation range, with the highest rate at the range of 4500–5100 masl. More than 6% of the new lakes were formed from 1990 to 2015 within the 4500–5100 masl elevation range, and they expanded by about 6.6%.

11.5 Institutional Collaboration

The need for a comprehensive database on glaciers and glacial lakes in Afghanistan emerged in a number of consultations carried out with the stakeholders. However, instead of carrying out the task all by itself, SERVIR-HKH adopted the approach of co-development where NWARA was an equal partner in the implementation process. A team of six professionals was formed at NWARA, including two nominated by NWARA and four research associates supported by SERVIR-HKH. The team worked solely on the mapping application and were trained, guided, and supervised by the SERVIR-HKH staff at ICIMOD. The main objective of this approach was to enable NWARA to carry out such exercises independently by Afghan professionals in the future.

11.5.1 Capacity Development

The capacity development of Afghan professionals on glacier and glacial lake research has been one of the successful endeavors in SERVIR's institutional capacity-building initiative. The experts from ICIMOD provided several hands-on and on-the-job trainings to initiate the work. In the beginning, a general hands-on training program was organized at GDWR to foster a better understanding about glaciers and glacial lakes and to develop the participants' ability to generate and use data on their own for monitoring and assessing glaciers and glacial lakes in Afghanistan. Later, the team of six staff at NWARA was provided several on-the-job trainings for preparing the glacier and glacial lake database of Afghanistan (Fig. 11.10). The team proved successful in preparing the database and in developing a detailed analysis report; this was carried out under the direct supervision and with technical guidance from the experts at ICIMOD. Through this overall exercise, the team has developed the skills and confidence in applying RS and GIS techniques in the mapping, monitoring, and assessment of glaciers and glacial lakes. Then, the team members, as resource persons, organized several

Fig. 11.10 On-the-job training at ICIMOD for the team preparing the glacier and glacial lake database. Photo by Jitendra Raj Bajracharya

Fig. 11.11 The mapping team being provided training on glacier mapping and monitoring. Photo by Esmatullah Joya

trainings for other professionals in NWARA, thus replicating the capacity-building efforts in a more sustainable way (Fig. 11.11).

11.5.2 Dissemination

The first comprehensive glacier database of Afghanistan was launched at a dissemination workshop (Fig. 11.12) on 2 July 2018, and Glacial lake database was launched on 23 Nov 2020 which were organized at the NWARA office in Kabul. An online application was also launched during the occasion which provides access to the database and an interactive visualization of the glaciers and the changes over time. The general public, students, and researchers can also access glacier and glacial lake data for all periods through the Regional Database System (RDS), ICIMOD website (rds.icimod.org).

The professionals and policymakers at the dissemination workshop emphasized the importance of the glacier database and portal for better management of water resources in Afghanistan. The discussions also touched upon the following: the need to validate data through field surveys; the use of high-resolution imagery in the case of some selected glaciers for further detailed study on glacier melts and mass balances; and the installation of automatic weather stations and hydro-climatic stations in some of the selected glaciers so that there would be more in-depth understanding about glaciers as well as more realistic information on the

Fig. 11.12 Participants of the dissemination workshop held at NWARA on 2 July 2018. Photo by Utsav Maden

glacier-melting processes. The professionals also called for better coordination among all the stakeholders concerned, including academicians, to enable longer-time monitoring of the glaciers. Further, they sought the support of all the relevant organizations to ensure the sustainability of the database and its efficient use.

11.6 Lessons Learnt

The main aim of SERVIR-HKH was to build the capacity of the national professionals of Afghanistan on the application of EO and GIS technology for glacier and glacial lake mapping and monitoring while generating a national database. Since the engaged professionals did not have a previous background of working on EO and glacier mapping, the initial trainings were quite taxing. Moreover, the experts at ICIMOD had to guide and supervise the team in Kabul remotely which was quite challenging and required many iterations for the finalization of the database.

There were also technical challenges in the mapping processes. The NDSI and NDWI indices are effective in mapping CI glaciers and glacial lakes, but not for mapping larger areas as that involves hindrances such as shadows, clouds, seasonal snow, turbid/frozen pro-glacial lakes, and some permanent snow cover. In this context, the algorithms do not work properly in the case of the ice in the shadow areas and for turbid or frozen pro-glacial lakes. These regions need to be checked carefully and need some manual correction. But there exists no best algorithm for DC glacier mapping which can be applied for the larger regions without some manual corrections of the boundaries and terminus. The smooth textural surface of the debris-covered part compared to other regions in the HKH added more challenges in accurately delineating its boundary and terminus. The textural variation between the DC glaciers and its surrounding moraine and barred rock areas was difficult to differentiate through the Landsat images. Also, cross-checking of the higher-resolution images in the Google Earth environment was not possible due to the low quality of the images. Hence, the manual correction of the debris-covered part required special attention.

11.7 Way Forward

Based on Landsat images, the study provides a comprehensive picture of the status and changes in glaciers and glacial lakes over the period of a quarter century—from 1990 to 2015. This is a big achievement for Afghanistan. The generated data can also be utilized in monitoring and understanding the dynamics of glacier and glacial lakes in the future and for other purposes such as for modeling the availability of water resources, glacial hazard prediction, and to know more about the impacts of climate change on glaciers.

Apart from this information, the project also strengthened cooperation and collaboration with local partners and enhanced their knowledge on the mapping and monitoring of glaciers and glacial lakes. The trained human resources in this area of mapping and monitoring are indeed a great asset to the country and can contribute significantly to the vital area of water management. Now the system should be further developed to enable regular monitoring, at least at five- or ten-year intervals, so that the relevant agencies are up to date about the trends in glacial changes. More investigations are also required in spheres such as geodetic glacier mass changes, glacio-hydrological models, and glacier and snowmelt modeling. This will come in handy in important catchment areas and give a clearer picture on the availability of water resources, the risks of glacial hazards, and on the overall changes in the glacial environment. It can also be utilized to identify some representative glaciers for long-term in situ monitoring.

Since Afghanistan is an arid and semi-arid country, irrigation is essential for food production. Any in-depth information on the country's glaciers and their run-off would be of critical value to establish a reliable and equitable irrigation system; and this would have positive impacts on agricultural productivity, food security, and income, while also reducing the vulnerability of farmers to droughts.

Most of Afghanistan's rivers have hydropower potential. It is estimated that the country can generate 23,000 MW of hydropower (Ahmadzai and McKinna 2018). In such a scenario, a scientific documentation of the present and periodic changes in glacial lakes would be valuable when it comes to constructing hydropower plants upstream, near glacial lakes, and in identifying the risks involved in building a particular plant.

Coming to GLOFs, the time-series glacial lake data can be utilized to identify the potentially dangerous glacier lakes in the country and to list the lakes in terms of their danger quotient. A GLOF risk reduction strategy should be established not only to reduce risk but also to increase the resilience of the vulnerable communities. A policy should also be developed to strengthen national and institutional capacities in the establishment of GLOF-resilient development pathways.

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Chapter 12
The High-Impact Weather Assessment Toolkit

Patrick N. Gatlin, Jonathan L. Case, Jayanthi Srikishen, and Bhupesh Adhikary

12.1 Introduction

Of the various types of weather phenomena, thunderstorms produce some of the most immediate and impactful hazards—damaging winds and hail, frequent lightning, and intense rainfall. Resilience to high-impact weather can be attained through investment in several key areas: proper infrastructure; effective emergency management; public education; and well-informed weather forecasting services. Unfortunately, some of the most intense thunderstorms occur in developing nations that have yet to build sufficient resilience to such weather hazards. Although there is a perceived cost associated with establishing National Hydrological and Meteorological Services (NHMS), investment in these services can boost the socioeconomic well-being of a developing nation (e.g., Nepal) by a factor of 10 (Perrels 2011). Early warning services are identified as providing the greatest and most immediate socioeconomic benefit amongst other types of disaster risk reduction strategies (Hallegatte 2012).

The Hindu-Kush Himalaya (HKH) region is host to some of the most intense thunderstorms on Earth (Zipser et al. 2006), primarily during the pre-monsoon season (Cecil and Blankenship 2012), and is routinely plagued by the hazards they pose (e.g., Das et al. 2014; Bikos et al. 2015; NIRAPAD 2018). Their impact is

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_12

especially felt in Bangladesh where many documented tornado events have caused hundreds of fatalities, including over 700 in one event in April of 1996, and at least 1300 in a single event on 26 April 1989 (Bikos et al. 2015). A recent notable thunderstorm event in Bangladesh occurred on 30 March 2018, causing 282 casualties (at least six of them fatal), damaging 943 houses, and destroying large swaths of crops as a result of a tornado and other strong winds and large hailstones (222 of the casualties solely due to hailstones; NIRAPAD 2018). Furthermore, lightning vulnerability has become more prominent in Bangladesh with more than 250 fatalities recorded per year from 2010 to 2016 (Dewan et al. 2017). And, recent storm events on 29–30 April 2018 and 9–10 May 2018 produced widespread frequent lightning that resulted in 74 fatalities in Bangladesh.

Even though Nepal is less densely populated than Bangladesh, it has also suffered damages due to similar weather hazards (Fig. 12.1). On 31 March 2019, the first-ever documented tornado occurred in southern Nepal, leading to 30 deaths, 1150 casualties, and destroying 2890 homes (Mallapaty 2019; Shrestha et al. 2019). [It is likely that tornadoes occur in Nepal on a more regular basis during the pre-monsoon season but have historically gone undocumented due to the lower population density and lack of effective communication tools]. More prominent in Nepal have been hailstorms, such as the event in 2006 that caused crop and livestock damages which exacerbated local food shortages (ACTI 2006).

Although many NHMS in developing regions such as the HKH have access to weather forecasting tools, they currently lack the information required to support early warning services and timely disaster response that can help mitigate the impacts of hazards that are produced by frequent and intense thunderstorms. As these services undergo modernization efforts, which include enhancements in

Fig. 12.1 Weather hazard is a major issue in the mountains during monsoon seasons. Photo by Santosh Raj Pathak

observational infrastructure (e.g., Rigaud 2015; World Bank Group-PPCR 2015; World Bank 2017), investments in new computational tools that will support enhanced early warning services are also necessary.

12.2 Forecasting High-Impact Weather

Numerical weather prediction (NWP) is the primary tool used by NHMS to produce weather forecasts. In particular, the Weather Research and Forecasting (WRF) model (Powers et al. 2017) has become the most widely used regional forecast and simulation tool in the weather community (e.g., Kain et al. 2006; Tao et al. 2016; Schwartz et al. 2019), including by NHMS in the HKH region (e.g. Ahasan et al. 2014; Kotal et al. 2015). Operationally, the WRF model is typically configured to provide hourly regional weather forecast guidance up to three or four days. Although WRF is a powerful tool, it still cannot replace a sufficiently dense observational network when it comes to monitoring and nowcasting (i.e., 0–1 h forecasts) rapidly unfolding weather such as thunderstorms. However, in countries such as Nepal such observations are often limited due to the terrain or lack of investment in Doppler weather radar networks that are critical to assessing such high-impact storms. Thus, it is critical that NHMS possess highly relevant and skillful NWP to gain proper situational awareness of potential weather hazards during the forecast period.

12.2.1 Challenges of Forecasting Thunderstorms

Regional models such as WRF also require input from the global NWP in order to represent the initial state and evolution of the atmosphere on a larger scale that can orchestrate high-impact weather events through their interaction with land and ocean. Hence, it is important to properly represent the initial state of the land–atmosphere–ocean system for regional modeling applications, which entails bringing observations into the NWP framework via data assimilation methods. Since in situ observations are rather limited across the globe, NWP in such regions often incorporates the geophysical variables retrieved via satellite-based remote sensing into data assimilation algorithms using radiative transfer models to relate satellite observations to NWP model state variables (Barker et al. 2012; Geer et al. 2017). However, satellite retrievals are not straightforward and introduce additional uncertainty in the model initial conditions. Furthermore, there are a variety of data assimilation techniques, some of which can provide significant improvements to the forecast (e.g., Huang et al. 2009), but they can be rather complex and computationally expensive, especially for real-time applications.

Proper forecast of thunderstorm hazards requires the use of a convection-permitting model (i.e., its horizontal grid spacing must be on the scale of 4–5 km or finer). This model must adequately depict all physical processes and interactions between the land/ocean and atmosphere that lead to cloud and precipitation development and decay. Since explicitly simulating all of these interactions and processes is not feasible, they must be parameterized (i.e., approximated) within the model (Stensrud 2007). Convection-permitting (also referred to as cloud-resolving) models often include parameterizations of sub-grid-scale motions (e.g., turbulent motions within the boundary layer), mixed-phase microphysics, and radiative processes (Guichard and Couvreux 2017). Decades of research have gone into developing cloud-resolving models and parameterizations of these physical processes (Tao 2007). As a result, numerous parameterization schemes have been incorporated into the Advanced Research WRF for simulating thunderstorms (UCAR 2020). This is promising for improving the skill of model forecasts, but it requires choosing the appropriate ones for the application at hand. There have been a multitude of sensitivity tests of parameterization schemes (e.g., Milbrandt and Yau 2006; Cohen et al. 2015; Fan et al. 2017), but no single combination of parameterizations works best for all thunderstorm hazards, weather regimes, and geographical regions.

12.2.2 Ensemble-Based, Convection-Allowing NWP

In light of this wide variety of potential configurations, model uncertainty, and differing assumptions within individual parameterizations, a solution has been to perform ensemble NWP by running a suite of different model runs. Each model run may be configured with a different combination of parameterizations and/or initial conditions. The main idea of ensemble NWP is to capture the range of possible solutions (e.g., Fig. 12.2), and thereby enable probabilistic-based forecast information that facilitates a more well-informed decision. To improve thunderstorm forecasts in the United States, regional WRF-based convection-allowing models (e.g., Kain et al. 2006, 2010) have been used in an ensemble configuration (e.g., Clark et al. 2012; Schwartz et al. 2019) to support severe weather and excessive precipitation forecast experiments in the National Oceanic and Atmospheric Administration (NOAA) annual Hazardous Weather Testbed's Experimental Forecast Program (Clark et al. 2012). This particular forecast system included over two dozen different model simulations that produced hourly forecasts out to 30 h at convection-allowing grid spacings (1–4 km) spanning the continental U.S. Similar experimental ensemble forecast demonstrations have been undertaken by the National Center for Atmospheric Research (NCAR) and have received much fanfare from the weather community (Schwartz et al. 2019), but their relatively large computational burden hinders their implementation by operational agencies with relatively limited resources.

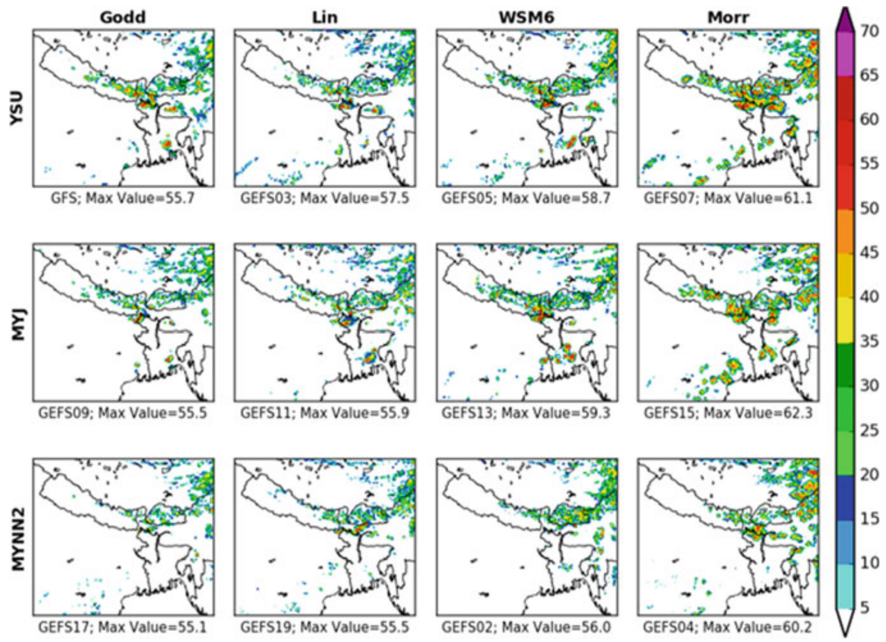

Fig. 12.2 An example of the range of different weather scenarios produced at the same forecast hour. Shown is the composite reflectivity, a metric for gauging thunderstorm intensity, which was produced by the HIWAT ensemble WRF runs on 25 April 2019. Traditional approaches to operational NWP only provide a solution based on a single model run (e.g., top-left panel), which may not be the correct one given the uncertainty in the model-based representation of the atmosphere and its evolution. Hence, ensemble-based NWP provides a variety of solutions that can be combined to obtain the probability of a weather hazard at any point in the forecast cycle

12.3 A High-Impact Weather Service for the HKH Region

In response to the need to build the resilience of the HKH region to high-impact weather, NASA SERVIR developed a new tool for use by NHMS in the region. The High-Impact Weather Assessment Toolkit (HIWAT) is a service that provides probabilistic-based thunderstorm hazard forecast guidance to NHMS forecasters and other weather-sensitive decision makers. HIWAT uses a convection-allowing ensemble modeling system similar to that developed for experimental hazardous forecast demonstrations in the U.S. (e.g., Clark et al. 2012; Schwartz et al. 2019), but it is tailored for NHMS in the HKH region.

12.3.1 Model Configuration

The WRF model is configured in HIWAT using an outer domain with 12-km grid spacing centered on South Asia, a 4-km inner domain that includes Nepal, Bangladesh, Bhutan, and north-eastern India (Fig. 12.3), and 42 terrain-following vertical levels ranging from the ground to a barometric altitude of 20 hPa.

The larger 12-km domain is primarily used for regional synoptic-scale situational awareness and, more importantly, to downscale the boundary and initial conditions obtained from the larger global-scale model to the higher-resolution nested grid. The 12-km resolution outer domain parameterizes convection using the Kain-Fritsch scheme (Kain 2004). On the 4-km domain, the cumulus parameterization is turned off to explicitly simulate convective storms (i.e., convection-allowing). Although a higher resolution would likely result in a more accurate representation of the convective processes and subsequent thunderstorm intensity (e.g., Potvin and Flora 2015), the resolution used in HIWAT is a trade-off between reducing the computational burden while retaining the capability to forecast the hazards posed by mesoscale weather systems (e.g., Weisman et al. 1997; Bryan and Morrison 2012).

For simulating thunderstorms, the representation of the planetary boundary layer (PBL) processes that lead to convective initiation and the microphysical processes that result in precipitation development are key. Hence, the HIWAT ensemble forecasting system has diversity in the parameterization of the PBL and microphysics (Table 12.1). Each of the microphysical schemes account for riming (i.e., formation of graupel/hail)—a critical process in the development of deep convective storms and lightning (see review by Williams 2001). To include additional

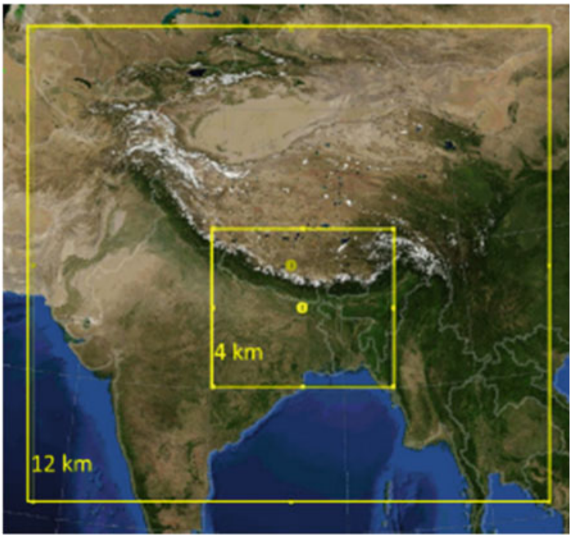

Fig. 12.3 Map of HIWAT domains over Asia

Table 12.1 Ensemble configuration of the 4-km resolution domain of the WRF-based probabilistic forecasting system used in HIWAT-HKH

Key: *ensemble member* initial condition		Microphysical parameterization			
		Goddard (Tao et al. 2016)	Purdue Lin (Chen and Sun 2002)	WSM6 (Hong and Lim 2006)	Morrison 2-moment (Morrison et al. 2009)
PBL parameterization	YSU (Hong et al. 2006)	*HKH1*: GFS	*HKH2*: GEFS 03	*HKH3*: GEFS 05	*HKH4*: GEFS 07
	MYJ (Janjić 1994)	*HKH5*: GEFS 09	*HKH6*: GEFS 11	*HKH7*: GEFS 13	*HKH8*: GEFS 15
	MYNN2 (Nakanishi and Niino 2009)	*HKH9*: GEFS 17	*HKH10*: GEFS 19	*HKH11*: GEFS 02	*HKH12*: GEFS 04

The NCEP/EMC model used for initial/boundary conditions is listed beneath each named ensemble member

diversity and spread in the HIWAT ensemble, the initial conditions are varied. The operational run of the Global Forecast System (GFS; Zhou et al. 2019) and members from the Global Ensemble Forecast System (GEFS; e.g., Guan et al. 2015; Zhou et al. 2017), which are run every 6 h by the U.S. National Centers for Environmental Prediction (NCEP) Environmental Modeling Center's (EMC) and freely obtained from them, are used to initialize the WRF model employed by HIWAT. Also, HIWAT ingests a 2-km resolution, northern-hemispheric sea surface temperature (SST) composite product derived from NASA's MODIS and VIIRS satellite measurements (Zavodsky et al. 2017), which improves upon the considerably coarser SST analysis in the GFS/GEFS models. To execute the ensemble WRF model runs, HIWAT employs the Unified Environmental Modeling System (UEMS; Rozumalski 2019), which greatly simplifies the complex workflow involved in NWP by managing data acquisition, initialization, pre- and post-processing, and generating derived fields.

12.3.2 Probabilistic Forecast Products

The primary guidance products generated by HIWAT are probabilistic forecasts of the thunderstorm hazards associated with tornadoes, damaging wind and hail, frequent lightning, and intense rainfall. These are provided at each hour of the forecast cycle and temporally composited into daily summary probability maps that can readily facilitate the convective outlooks of thunderstorm hazards (Fig. 12.4), which is a capability recommended in the report on the Bara-Parsa (Nepal) tornado of 31 March 2019 (Shrestha et al. 2019). Furthermore, products such as daily summaries provide a weather-sensitive decision maker the information in a concise

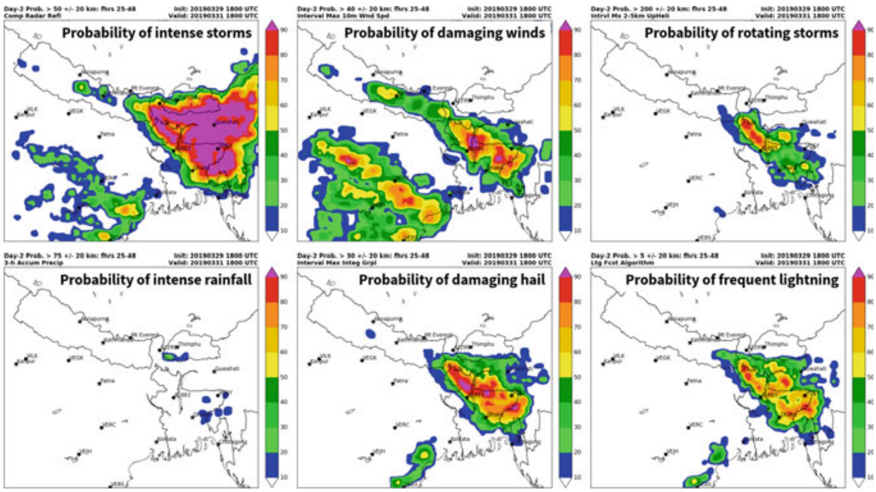

Fig. 12.4 HIWAT probabilistic forecast of thunderstorm-related weather hazards for the Day-2 time period. Intense storms are defined as composite reflectivity exceeding 50 dBZ. Damaging winds are defined as the maximum 10-m wind speed in the previous hour (Kain et al. 2010) exceeding 40 kts. Rotating storms are defined as the maximum 2–5 km updraft helicity (Kain et al. 2008) in the previous hour exceeding 200 m^2s^{-2}. Intense rainfall is defined as the 3-hour accumulated precipitation exceeding 75 mm. Damaging hail is defined as the maximum column-integrated graupel in the previous hour (Kain et al. 2010) exceeding 30 kg m^{-2}. Frequent lightning is defined as one lightning flash per minute produced by the diagnostic WRF Lightning Forecast Algorithm (McCaul et al. 2009, 2020)

manner to quickly assess future thunderstorm impact(s). Because of uncertainties in model forecast accuracy, combined with convective features that typically have relatively small footprints (e.g., Kain et al. 2010), a 20-km spatial neighborhood (i.e., grid points within 20 km) is first applied to the individual ensemble member thunderstorm hazard fields prior to computing the probabilities. Additionally, a Gaussian smoother is used to produce smoother and more visually appealing probability maps. Such neighborhood approaches can result in more skillful probabilistic forecasts (Schwartz and Sobash 2017).

An example of the Day-2 summary forecast from HIWAT (i.e., a 25–48 h forecast period) is shown in Fig. 12.4. This gives the probability of the indicated weather hazard within 20 km of a point at any time of the Day-2 forecast period. Using composite reflectivity exceeding 50 dBz as a proxy for storms with significant precipitation rates (i.e., intense storms), we see there is greater than a 90% probability of intense storms occurring from southeastern Nepal across northern and eastern Bangladesh into southern Bhutan and Northeast India. A Day-2 convective outlook would highlight this region. The next question is the likelihood of specific hazards within this region. We see intense rainfall that might lead to flash-flooding should not be a major concern, but there are greater probabilities of damaging winds, hail, rotating storms, and frequent lightning across this region of intense storms. Furthermore, the higher probability of rotating storms in northern Bangladesh being aligned with the relatively enhanced probability of damaging wind and hail suggest that tornadoes are more probable in northern Bangladesh than in eastern Bangladesh. This analysis of Fig. 12.4 is akin to the forecast process used by NOAA's Storm Prediction Center in the U.S. to determine future convective hazards (Jirak et al. 2014).

12.4 HIWAT Forecast Demonstrations

Two forecast demonstrations of HIWAT took place during the pre-monsoon (March-May) and monsoon seasons (June–August) of 2018 and 2019, with the Bangladesh Meteorological Department (BMD) and Nepal's Department of Hydrology and Meteorology (DHM). For these demonstrations, HIWAT used the public release of WRF version 3.7.1 (included in UEMS version 15.99.1), while NASA's SERVIR program provided the virtual computing cluster needed to run it. This virtual cluster consisted of 13 nodes, each with 16 dual-core Intel Xenon 2.10 GHz processors and 128 GB of RAM. It produced 0–48 h HIWAT-HKH forecast products within 6 h of HIWAT initialization. This resulted in a probabilistic forecast guidance covering two diurnal maximums in the convective activity in the HKH region (e.g., Romatschke et al. 2010; Mäkelä et al. 2014; Dewan et al. 2018).

During these demonstrations, HIWAT trainings were held in Kathmandu and Dhaka to familiarize the operational forecasters at DHM and BMD with HIWAT and its probabilistic-based thunderstorm hazard forecasting products. The products were made available to forecasters via two web-based display tools. An image viewer, which was contributed and hosted by NASA's Short-term Prediction Research and Transition Center (SPoRT; Jedlovec 2013), provided quick looks and animations of all current and archived HIWAT forecast products. Also, select HIWAT products were packaged (i.e., separate from the full model output suite) into a netCDF format for an interactive (i.e., pan, zoom, query) web-based application, which was produced within the Tethys platform (Nelson et al. 2019), to enable efficient interrogation of the forecasts within a web-mapping service. The Tethys-based HIWAT Model Viewer App (Fig. 12.5) provides users with the capability to quickly determine where, when, and how likely a thunderstorm hazard may occur. It also has the capability to provide the spatiotemporal statistics of a forecast variable (e.g., as to when maximum rainfall will occur within the selected area). Figure 12.5 shows the HIWAT forecast run from 29 March 2018 which indicates that a high-impact weather event is possible across the northern half of Bangladesh. The time-series plots of the forecast across this area show a greater than 60% chance of rotating thunderstorms, with a 45–55% chance of damaging winds and hail at the selected points between 11:00 and 15:00 UTC on 30 March 2018.

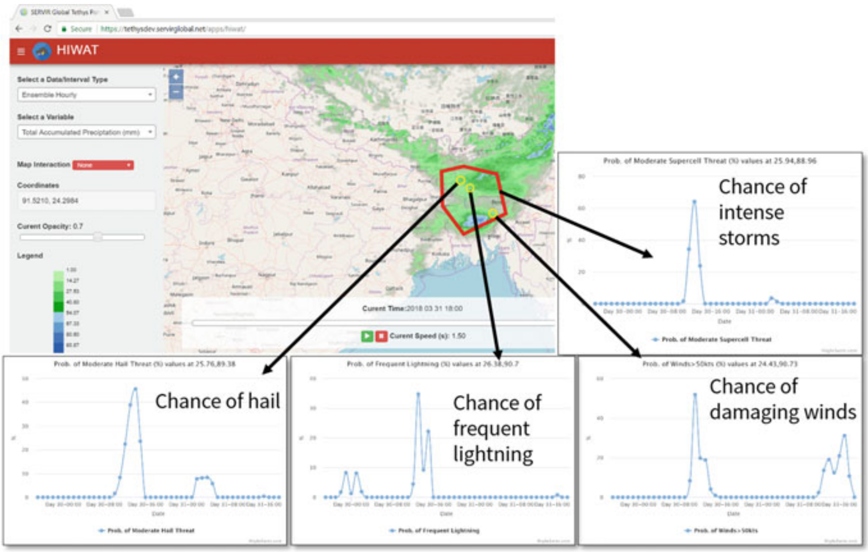

Fig. 12.5 The Tethys-based HIWAT model viewer app

12.4.1 Hailstorm: 30 March 2018

The severe thunderstorms that occurred across the eastern HKH on 30 March 2018 caused significant damages in Nepal, Bangladesh, and Northeast India (Fig. 12.6). In Bangladesh alone, over 274 casualties, numerous acres of crops, and several hundred houses were damaged, mostly due to large hail but also due to strong winds, and a tornado in Nepal's south-central districts of Bara and Parsa (Shrestha et al. 2019). The Day-1 probabilistic forecasts from the HIWAT-HKH runs, initialized at 18:00 UTC on 29 March 2018, are shown in Fig. 12.6a–c. They clearly indicate more than an 80% chance of hailstorms in northern and central Bangladesh and Meghalaya in north-east India (Fig. 12.6a). The forecast hotspots of frequent lightning overlap with this region (Fig. 12.6b), but they also extend further east, including Assam in Northeast India and Sylhet division in northeastern Bangladesh. It also shows a greater than 80–90% chance of 10-m AGL winds exceeding 50 kts ($\sim$93 km h^{-1}) in Sylhet (Fig. 12.6c).

Direct, near real-time observations of storm intensity are sparse in the rural areas of the HKH region; hence, HIWAT also consists of a satellite-based observational component to facilitate assessment of its forecasts. On 30 March 2018, at around 08:11 UTC, there was an overpass of the HKH region by the GPM Microwave Imager (GMI) onboard the GPM core satellite (Skofronik-Jackson et al. 2017). Passive microwave observations provided a measure of storm intensity through their sensitivity to the upwelling radiation at 37 GHz being scattered by precipitating ice such as hail (Spencer et al. 1987; Cecil 2009). Applying the empirical fits

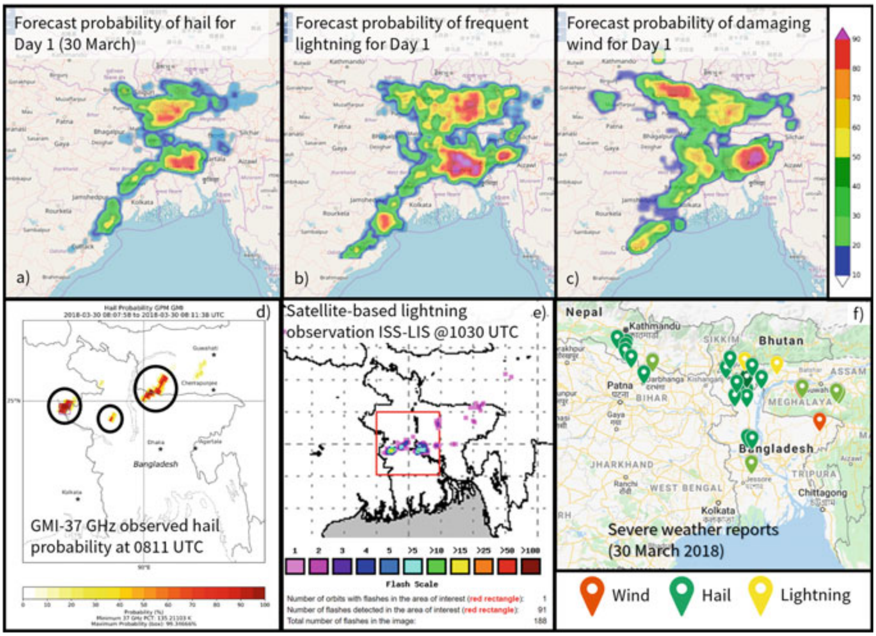

Fig. 12.6 Performance of the HIWAT forecasts for the 30 March 2018 high impact weather event. **a–c** The 29 March 2018 forecasts from HIWAT-HKH indicate that thunderstorm-related hazards are highly likely to occur across parts of the eastern HKH on 30 March 2018. **d**, **e** Precipitation and lightning observations from the GPM core satellite radiometer and Lightning Imaging Sensor onboard the International Space Station, respectively, during overpasses of the eastern HKH region on 30 March 2018. **f** Location of damaging wind, hail, and lightning due to a high impact weather event in the eastern HKH region on 30 March 2018

of Bang and Cecil (2019) that relate the polarization-corrected brightness temperature at 37 GHz to the probability of hail observed at the ground, the GMI observations indicated three intense storms over the region with a greater than 75–95% chance of producing damaging hail at the ground, especially in north-western Bangladesh and west of Cherrapunjee, India (Fig. 12.6d). Similar damaging hail probabilities had been found for these storms with measurements from the Advanced Microwave Scanning Radiometer 2 (AMSR2) during its overpass about 30 min earlier (not shown). These patterns aligned with the northern-most local maxima of the hail probability forecast by HIWAT (Fig. 12.6a). Also, observations collected with the Lightning Imaging Sensor onboard the International Space Station (ISS) (Blakeslee et al. 2020) during an overpass at 10:30 UTC depict three individual thunderstorms with relatively higher lightning flash activity over central Bangladesh where the HIWAT forecasts suggested nearly a 100% chance of frequent lightning (Fig. 12.6e). Finally, the reports of thunderstorm-related damage, although likely incomplete and affected by subjective reporting, largely corroborated the HIWAT Day-1 forecasts that strongly suggested a high-impact weather event unfolding from eastern Nepal to Northeast India and central Bangladesh (Fig. 12.6f).

12.4.2 Lightning

Lightning-related casualties have increased in Bangladesh in recent years (Dewan et al. 2017; Holle et al. 2018), so much so that the government declared lightning as a national disaster in 2016. During the 2018 pre-monsoon season, there were 275 reported casualties (215 of them fatal) due to lightning in Bangladesh, with 181 of these occurring during a two-week period in late April and early May (Fig. 12.7a). Although agricultural practices in Bangladesh during the annual peak lightning months of April and May contribute to the vulnerabilities (Dewan et al. 2017; Holle et al. 2019), a lack of capacity to forecast lightning is also a factor.

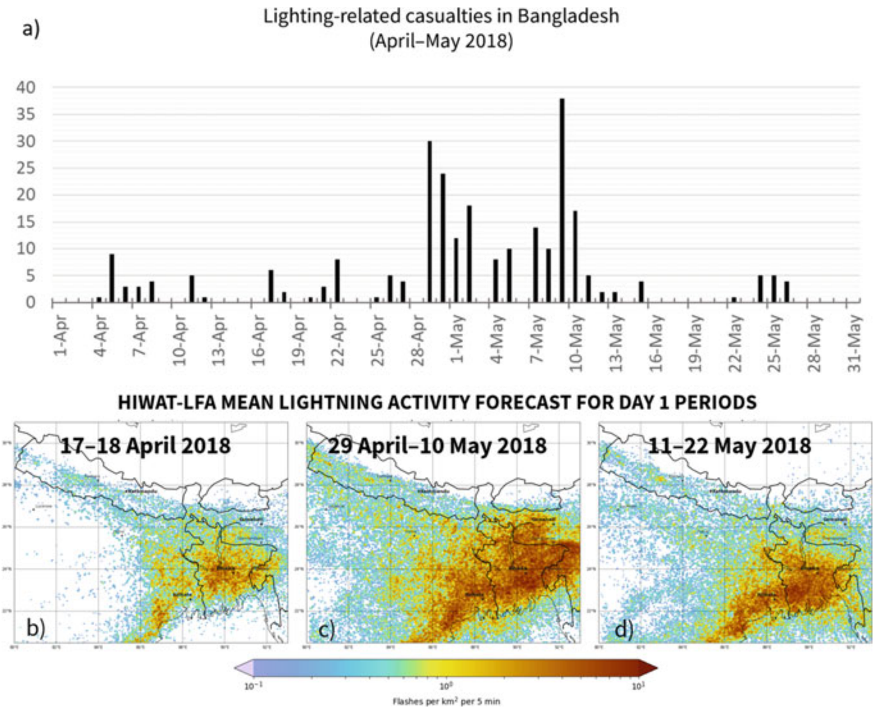

Fig. 12.7 Impact of lightning activity on Bangladesh and select forecasts from HIWAT-HKH during April and May 2018. **a** Lightning-related casualties reported in Bangladesh between April and May 2018 (*Source* NIRAPAD 2018). **b–d** The mean 24-hour (i.e., Day-1) forecast flash rate density from the HIWAT-HKH ensemble for three different periods centered on the peak number of lightning-related casualties in panel a

One of the tools used in HIWAT is the Lightning Forecast Algorithm (LFA), which uses the convection-allowing WRF-simulated fields important to the storm electrification process as inputs, and computes a calibrated total lightning (both cloud-to-ground and cloud flashes) flash rate density (McCaul et al. 2009, 2020). This total lightning prognostic field is produced for each of the HIWAT ensemble members to produce the hourly and daily probabilistic lightning forecasts across the model domain (e.g., Figs. 12.5 and 12.6). Figure 12.7b–d provides a daily summary of the HIWAT lightning forecasts from 17 April to 22 May 2018. The amount of lightning being forecast increases from mid-April to early May, then decreases by mid-May, especially across northeastern Bangladesh and Northeast India. This trend compares very well with the trend in lightning casualties reported in Bangladesh during this time period (Fig. 12.7a). Also, Holle et al. (2019) found that the farming districts in northeastern Bangladesh are especially susceptible to lighting-related fatalities during April and May. Lightning safety education, especially related to agricultural practices (e.g., best times of day to tend or harvest crops), can greatly help reduce the adverse impacts of thunderstorms in the region. However, it is not every day that thunderstorms will occur in the same location at the same time, and it is not practical to halt work every afternoon during the peak harvesting months (April and May) of Boro rice, potato, and wheat. Hence, access to more informative weather forecasts such as those provided by HIWAT can facilitate better planning of day-to-day activities.

12.4.3 High-Intensity Rainfall Forecasting

Another reason for using ensemble NWP is to enable the forecasting of flash floods in the regions affected by localized, intense rainfall associated with thunderstorms (Fig. 12.1). In an ensemble system such as HIWAT, hydrologists can access the information provided by the system's multiple precipitation forecasts in such a manner to concisely convey the expected outcome with a higher degree of confidence. This can be in the form of probabilities of rainfall exceeding some threshold in a given basin, which may not be readily known, or in the form of an envelope of streamflow forecasts for each basin. Most streamflow models require a single deterministic input of precipitation instead of a probability of precipitation. However, simply averaging the precipitation forecasts of each ensemble member will simultaneously over-predict the areal coverage of rainfall and reduce the amplitude of more intense rainfall events that are often the cause of the flash flooding in the smaller basins and urban areas. Hence, HIWAT employs a statistical technique known as the probability matched mean (PMM; Clark 2017) to provide a single precipitation forecast that represents a "most probable solution" from all its ensemble forecast members. The PMM not only retains the higher-amplitude precipitation intensity from the individual ensemble members but also retains the more spatially accurate pattern of the ensemble mean, with the bias at any precipitation threshold being about the same as the average bias of the

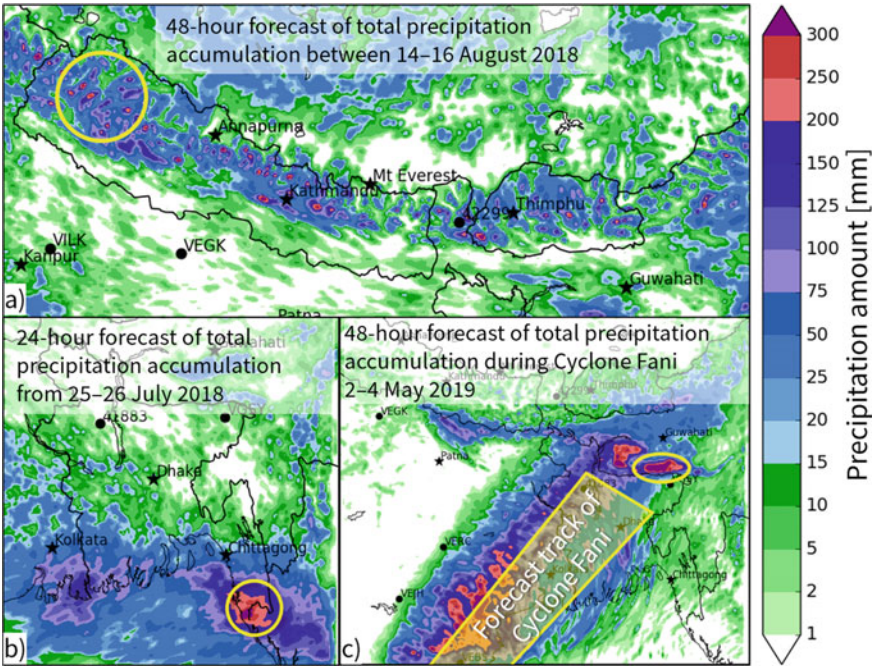

Fig. 12.8 Examples of HIWAT-HKH ensemble precipitation forecasts using the PMM method. The circled regions indicate areas where extreme rainfall was observed within a 1–2 day period, as discussed in the text

individual members (Ebert 2001; Clark 2017). The PMM precipitation product reaps the benefit of an ensemble forecast and also provides the accumulations required by hydrologic applications.

Although HIWAT-HKH is largely focused on severe storms that occur in the HKH region during the pre-monsoon season, the 2018 and 2019 demonstrations were expanded to the wet monsoon season (June –September) at the request of the end users (i.e., DHM and BMD) and primarily for the purpose of flash-flood forecasting. A few events from 2018 to 2019 are highlighted in Fig. 12.8 to demonstrate the utility of the HIWAT PMM forecasts of precipitation during heavy rainfall episodes. The top panel of Fig. 12.8 shows the PMM-based forecast of precipitation exceeding 200 mm in several highly localized areas within the Himalayan foothills and mountains. Flash flooding was reported in several small basins in western Nepal between 15 and 16 August 2018, including a particularly devastating one along the Jhupra River in Nalgad of Jajarkot district (The Kathmandu Post 2018). The bottom panels of Fig. 12.8 show other heavy rainfall events captured by HIWAT-HKH. On 25 July 2018, the HIWAT PMM-based forecast indicated precipitation accumulation would exceed 300 mm within a 24-h period in southeastern Bangladesh, near Cox's Bazar (Fig. 12.8b). The BMD's automated weather station in Cox's Bazar recorded a 24-h rainfall accumulation of

315 mm on 26 July 2018. The third example (Fig. 12.8c) is the 48-h PMM-based precipitation forecast of the tropical cyclone Fani, which developed in the Bay of Bengal and made its landfall southwest of Kolkata, India, on 2 May 2019. The spread of the 12-member ensemble runs indicated that after landfall, Fani would move north-east along the coastline and significantly weaken as it crossed into Bangladesh. Typically, cyclones bring a significant flooding threat to Bangladesh, but according to the HIWAT forecast Fani carried a low risk of flooding as the heaviest corridor of rainfall was forecast to stay west of Bangladesh and in the Northeast Indian state of Meghalaya. The 48-h forecast predicted over 250–300 mm of rainfall around Cherrapunjee in Northeast India (Fig. 12.8c), where an automated weather station recorded 276 mm of rainfall between 3 and 4 May 2018.

The HIWAT demonstrations during 2018 and 2019 also included a hydrologic component in which the PMM-based forecast precipitation accumulations were used as input to the model of Routing Application for Parallel computation of Discharge (RAPID; David et al. 2011) in order to produce streamflow forecasts for the HKH region (Nelson et al. 2019). The HIWAT forecasts were used in this system primarily for forecasting flash floods due to intense rainfall in the smaller basins that are often not captured by the coarser-resolution global weather forecast models.

12.5 Summary, Challenges, and Way Forward

A probabilistic weather forecasting system such as HIWAT demonstrates the importance of ensemble-based NWP in building resilience to high-impact weather in the HKH region. The wealth of information it provides can improve decision-making and enhance weather services. Extreme-weather forecasting is often plagued with uncertainty and cannot be captured nor effectively conveyed through a single weather model. However, a convection-allowing ensemble forecasting system depicts a range of possible scenarios of intense thunderstorm hazards and thereby can help convey the amount of confidence and/or uncertainty of these hazards in the forecast. In order to effectively carry this out, the ensemble has to be properly configured to address the weather phenomena, including the uncertainty in the physical understanding and representation of it. Additionally, the ensemble forecasts, which may include hundreds of potential visualization products, must be made easily digestible for the decision makers. Some of these products for assessing potential threats from severe weather events have been presented herein and others can be found in a review by Roberts et al. (2019).

A big challenge for NHMS, especially in the case of developing nations, is the computational resources that are required by the ensemble weather forecasting systems. The computational load depends upon the number of ensemble members, the number and geographical size of the modeling domains, their spatial resolution, and the designated number of forecast hours. The complexity of the forecast system (i.e., workflow) must also be considered. Additionally, reliable and high-speed internet access is needed to obtain the global models that initialize and provide boundary conditions to regional forecast systems such as HIWAT. Another challenge for NHMS lies in the novelty of the ensemble NWP, especially as a tool for thunderstorm forecasting. Also, continued education on advancements in meteorological forecasting techniques are needed since many meteorologists in developing nations have not received formal training on probabilistic-based weather forecasting.

The HIWAT service was designed with these challenges in mind. Although the HIWAT demonstrations consist of 12 separate WRF runs, HIWAT is fully customizable (in terms of domain size, number of ensemble members, and forecast hours) to accommodate porting the service to other regions. Also, and just as important, the myriad outputs from the individual ensemble members are combined into a handful of meaningful products relevant to addressing high-impact weather. These products are designed to be efficiently interpreted and are used to effectively convey the probability of thunderstorm hazards. HIWAT has demonstrated to NHMS in the HKH region the capability to build or enhance its capacity to provide services related to extreme-weather events. However, local NHMS may need to collaborate with scientific researchers to further customize the toolkit using thresholds that are based on more geographically-specific observations. The default thresholds used in the HIWAT demonstrations are primarily based on investigations focused on severe weather in the U.S. Furthermore, while information on familiar meteorological variables such as temperature, humidity, pressure, and wind are available from many regional observation networks operating in developing nations, more detailed information is needed to assess the storm prediction fields provided by a system such as HIWAT. Weather radars, especially those with Doppler and polarimetric capabilities, and lightning detection networks can provide critical observational evidence to evaluate the performance of this type of convection-allowing modeling system as well as enable additional refinement of the toolkit. This process of obtaining appropriate data, analyzing it, and using it to fine-tune the system to address local needs underscores the need for governments to establish a collaboration between their NHMS and the research community, either locally or abroad.

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Chapter 13 Geospatial Information Technology for Information Management and Dissemination

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13.1 Introduction

Over the last few decades, the development of geospatial technologies has converged with a variety of formal information technology disciplines (Zwartjes 2018; Jackson and Schell 2009). The rapidly growing location-based services seamlessly integrate data and technologies from Earth observation (EO), Geographic Information System (GIS), Geographic Position System (GPS), and wireless and mobile communications (Huang et al. 2018). The emerging technologies for large-scale data storage, processing, and analytics and the increased availability and quality of the geospatial data have created unprecedented opportunities with broad implications for both technology and society (Liu et al. 2019). Today, we see the presence of various kinds of information systems in the Web, ranging from very basic data visualization to more advanced applications that do rigorous spatial analysis on the fly and present the results to the user over the Internet.

Looking back at the evolution of Geospatial Information Technology (GIT), the desktop GIS was prevalent in the world up until the early 2000s. Early Web mapping applications were mostly limited to simple interactive visualization of data as maps without much sophistication, and there were very few map servers available at the time, like Environmental Systems Research Institute (Esri) ArcIMS and Minnesota MapServer. Based on user requests, these servers generated maps in the form of images in formats such as Portable Network Graphics (PNG) and Joint Photographic Experts Group (JPEG) and sent them back to the Web browser for visualization of data. For each action on the user's part, such as zooming in or out, the map server generated new maps dynamically and sent the outputs to the user's browser. The servers back then were not powerful and could handle only limited

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_13

map requests at a time. When the number of visitors using the map exceeded the server's handling capacity, it would slow down and, at times, crash.

All of this changed in 2005 with the arrival of Google Maps and Google Earth which gave everyone access to geographic information in a fairly democratic way. The ability to explore one's neighbourhood in 3D through high-resolution satellite images and navigation tools instigated spatial thinking in common people who did not have any technical background or specialized skills (Goodchild and Janelle 2010). Google Maps relied on serving pre-generated map tiles for each fixed zoom level instead of creating dynamic maps upon getting requests from the users; this optimized the map services and made them efficient. Google Maps also provided a number of base maps such as street map, satellite image, and terrain that acted as reference maps while allowing the users to overlay their own data on top of them. This became the industry standard and was adopted by many other agencies in the world. Today, there are several base maps available from different organizations such as Esri, Google, OpenStreetMap, MapBox, and Carto, and Web mapping applications are mostly built using base maps and overlaying the users' own data on top of them.

There has been a corresponding evolution on the application development front. Appropriate JavaScript application programming interfaces (APIs) such as Leaflet, OpenLayers, ArcGIS JavaScript API, and Google Maps JavaScript API have become available primarily to develop such Web mapping applications. In addition, there has been tremendous advancement in mapping servers as well in the past two decades. These days, server technologies such as ArcGIS Server and GeoServer are quite powerful. They are capable of serving a huge volume of data, carry out on-the-fly GIS operations, and are able to handle requests from numerous clients. Further, they support Open Geospatial Consortium (OGC) interoperability standards like Web Map Service (WMS), Web Feature Service (WFS), and Web Coverage Service (WCS), thereby enabling users to access data from different mapping servers and integrate them in their applications using the client software of their choice.

Another technological innovation of recent times is cloud computing which is becoming increasingly common and popular across the globe. The cloud offers high scalability in terms of processing and storage capacity with different modalities of payment that suit the users. There are numerous cloud-based applications and solutions that we use on a daily basis (e.g. Google Drive, Dropbox, and Microsoft 365). Esri's ArcGIS Online, which is popular among the GIS community, runs on Amazon Web Services (AWS) and provides a content management system that allows users to create and share maps, stories, and applications without writing any single line of code. Taking it forward, the advent of geospatial cloud computing platforms has brought paradigm shifts in the way we use GIS and remote sensing. A large number of satellites—fitted with various sensors—capture the data of our planet regularly, producing a huge volume of data at various geographic and temporal resolutions. A number of EO data such as MODIS, Landsat, Sentinel, and Global Precipitation Measurement (GPM) are freely available and have provided an opportunity to develop data products that are useful to decision-makers in various application areas. In traditional desktop-based remote sensing, individual scenes of satellite imagery are acquired, and specialized image processing software is used to generate the data products. As such, it would take a long time to produce data products that cover whole countries, and this would become much more complex when it comes to developing regional-level data products for multiple time periods. The geospatial cloud computing platforms such as GEE, Radiant Earth, and AWS, on the other hand, provide access to a huge collection of EO and geospatial data along with powerful computing facility to carry out image processing and analysis at the planetary scale. As an alternative to these platforms, the Open Data Cube (ODC) offers free and open-source solution for access, management, and analysis of a large collection of EO and geospatial gridded data.

There are increasing atmospheric and hydrologic applications using land-surface models which deal with data assimilation from various sources with complex and large range of spatial and temporal scales. There has been considerable progress in the development of data assimilation on continental surfaces in conjunction with the EO systems (Jean et al. 2016). Such applications are made possible by using high performance computing (HPC) clusters that consist of a collection of server machines connected together. In fact, HPCs are also implemented on the cloud using service from any of the key providers such as AWS, Google Cloud, and Microsoft Azure.

13.2 Adoption of GIT at SERVIR-HKH

SERVIR-HKH emphasizes the use of EO and geospatial technologies for environmental monitoring, food and water security, natural resources management to improve the resilience of the region to the impacts of climate change and other shocks and stresses. To achieve these overarching goals, it focuses on improved awareness of and access to geospatial data, products, and tools and increased provision of user-tailored geospatial services for informed decision-making in the HKH region. The evolution of technologies and their applications in the global context has influenced the way SERVIR-HKH is exploiting the opportunities of GIT to serve the region. The HKH region, like elsewhere in the globe, has seen a great improvement in Internet connectivity, with its presence becoming more and more ubiquitous, along with a significant increase in bandwidth and a sharp decline in price (Digital Nepal Framework 2019; ITU 2020). These factors have contributed greatly to making the Web the preferred platform for developing tools and applications. Although ICIMOD had been serving various GIS data and applications to partners through the Internet, including simple Web mapping applications for visualization since early 2000, the real journey of developing Web-based services began with the launching of SERVIR-HKH in 2010. SERVIR-HKH has been closely following the technological advancement and trends globally in the field of GIT. It has worked towards bringing the latest innovative tools and solutions to the HKH region by customizing them as per the local needs in ICIMOD's regional member countries. The options for platforms and technologies and the development approaches adopted for different GIT solutions are presented in the following sections.

13.3 Platforms and Technologies

The choice of platforms and technologies is generally guided by the desired functions, technological development, market trends, and available resources. Being the global leader, Esri technologies have been the primary choice since the introduction of GIS by ICIMOD in the early 1990s (Chap. 1). The technology options and platforms have been more diverse in recent years. The adoption of cloud computing is growing and increasingly becoming mainstream across the globe. Big data is another trend that allows analysis of extensive sets of information to generate the desired knowledge products. Besides, mobile devices have taken both the business world and the personal realm by storm, and the number of applications have skyrocketed in recent years. The key technologies and platforms that are used for developing applications and information services under SERVIR-HKH are presented here.

Esri's ArcGIS Technology: ICIMOD has been using Esri technologies as one of the core components of its geospatial infrastructure. The institution has implemented Enterprise GIS using the ArcGIS enterprise geo-database, and ArcGIS Desktop is the primary GIS client software used by its staff members. Most of the online mapping applications under SERVIR-HKH to date have been developed using ArcGIS JavaScript API, along with maps published through ArcGIS Server. Also, a number of data visualization applications and Story Maps have been developed using ArcGIS Online technology. Further, Esri's Survey123 for ArcGIS is used to build mobile field data collection for various services under SERVIR-HKH. Nepal Forest Fire Detection and Monitoring System, Land Cover Dynamics in Bhutan, and Glacier Dynamics in Afghanistan are some of the examples of the use of ArcGIS Server technology.

Google Earth Engine and Google App Engine: GEE is Google's cloud-based platform that enables environmental data analysis at the planetary scale. The GEE platform has been used by SERVIR-HKH to develop a number of applications such as annual land cover mapping for the entire HKH region and in-season crop mapping in selected countries. In addition, it is being used for big data analysis in various application areas. Further, a combination of GEE and Google App Engine has been used to develop Web mapping applications that allow users to do on-the-fly data analysis and present the results to the users; for example, the analysis of the normalized difference vegetation (NDVI) anomaly and wheat area mapping for Afghanistan.

GeoServer, PostGIS/PostgreSQL, and OpenLayers: The GeoServer is a popular open-source Web map server that allows to share, process, and edit geospatial data. It implements OGC interoperability standards such as WMS, WFS, and WCS. The PostGIS, on the other hand, is a spatial database extension for the PostgreSQL database, and the combination of these two provides open-source solutions for storing spatial data in the object relational database management system. As for OpenLayers, it is a JavaScript mapping library that enables consuming maps published from various Web map servers and putting together interactive Web mapping applications. The combination of these open-source technologies has been used to develop applications, especially when the applications are deployed at the partner's end and the use of commercial software is not feasible.

Tethys Platform: The Tethys platform consists of a suite of free and open-source software (FOSS) developed by Brigham Young University (BYU). It allows the development of Web applications using its Python Software Development Kit (SDK) and provides access to its core software components through the API. It uses Python Django as the Web application framework, along with GeoServer, for publishing data as map services, and PostGIS/PostgreSQL for storing spatial data. Further, it allows the use of OpenLayers for embedding dynamic maps in the Web applications. A number of applications under SERVIR-HKH have been built using the open-source Tethys platform. Some of the applications developed in the Tethys platform include the Regional Drought Monitoring and Outlook System for South Asia, Agriculture Drought Watch for Nepal, Bangladesh, and Afghanistan, and Streamflow Prediction for Nepal and Bangladesh.

Thematic Real-time Environmental Distributed Data Services (THREDDS) Data Server: The THREDDS Data Server is a Web server that provides metadata and access to scientific data sets. It integrates other open-source frameworks like the Open-source Project for a Network Data Access Protocol (OPeNDAP), OGC, WMS, WCS, and Hypertext Transfer Protocol (HTTP) to provide data access to its users. The THREDDS Data Server has been used to host many time-series data model runs like the High Impact Weather Assessment Toolkit (HIWAT), Routing Application for Parallel computation of Discharge (RAPID), and the South Asia Land Data Assimilation System (SALDAS).

SOCRATES: The HPC refers to the practice of aggregation of computing power that delivers much higher performance than one could get out of an individual desktop computer or workstation for solving large problems in science, engineering, or business systems (Sravanthi et al. 2014). The HPC can be achieved by creating a cluster that consists of a number of independent computers linked with the computation network; they act as a single computer which enables the processing of large data sets and solves complex computational problems at high speed using parallel processing techniques (Aydin and Bay 2009). The SERVIR Operational Cluster Resource for Applications—Terabytes for Earth Science (SOCRATES)—is an HPC cluster which has been established by SERVIR Global and is used by various SERVIR hubs as a shared resource. It is used to run the HIWAT system by SERVIR-HKH.

Amazon Web Services (AWS): Apart from on-premises servers, SERVIR-HKH also uses AWS to implement a number of online applications. For example, the Regional Drought Monitoring and Outlook System for South Asia and National Agricultural Drought Watch (Nepal) have been hosted on AWS.

Open Data Kit (ODK): ODK is a free and open-source software that allows rapid development and deployment of Android mobile-based data collection application. Along with Survey123, the ODK Collect has been used extensively for field data collections under SERVIR-HKH. For example, in the past, an ODK-based crop survey application was developed and used in collecting crop-related information in Nepal.

13.4 Development Approach

SERVIR-HKH follows a standard set of procedures when it comes to the development of services and related applications. Stakeholder consultation workshops and meetings are held to capture the requirements for each of the services in the countries where they are being built for. SERVIR-HKH uses the service planning approach wherein the users are placed at the centre at each stage of the design and development process (Chap. 2). The consideration of who the primary and secondary users are, what their needs are, and how the service will address those needs in terms of tackling issues on the ground is given utmost priority while designing and developing data products and applications. The tools and applications are designed and developed in close consultation with the primary users. Workshops and meetings are conducted to also capture the requirement regarding how the users will interact with the application. Regular meetings and exchanges are held with the primary users to gather their feedback at various stages of system development.

The institutional capacity of partners in terms of their existing IT infrastructure and technical skills are assessed to identify the gaps that need to be fulfilled to operationalize the services. The capacity building activities are embedded in the service development process such that the partners' technical capacity in terms of understanding and using the tools and information products of the services are built along with the development of the services.

Co-development is one of the key mantras of SERVIR-HKH, and wherever possible, it works jointly with its key partners in developing applications. For example, SERVIR-HKH and NASA's Applied Science Teams (ASTs) worked closely together to develop customized data and applications for various services such as Agriculture Drought Watch for Nepal and Streamflow Prediction for Nepal and Bangladesh. Together, they also regularly interfaced with key national agencies in generating and validating data products and developing customized applications to meet their requirements.

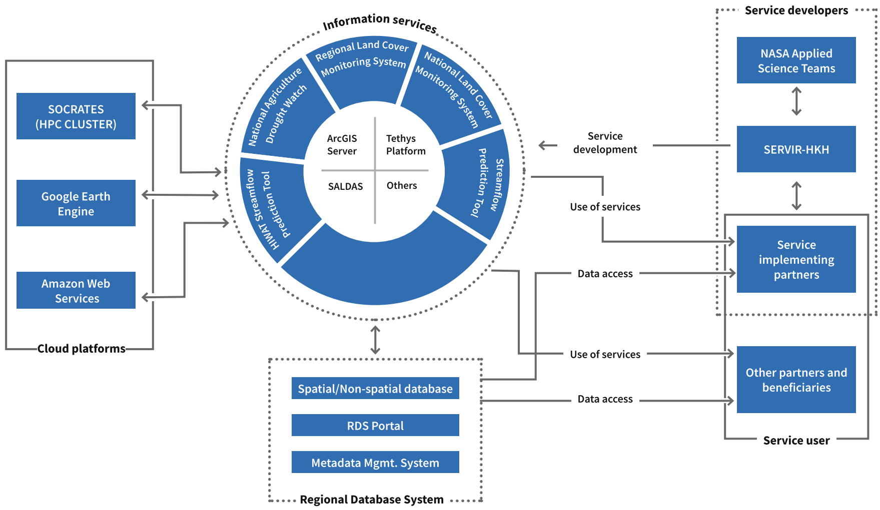


Fig. 13.1 Different components of SERVIR-HKH information services

SERVIR-HKH has also developed standard design templates for the front end of Web-based applications so that all the applications that are developed will have a similar look and feel irrespective of the technologies used at the back end. Nonetheless, the Web interface of the application is further customized in cases where the common standard template is not sufficient in providing tools, components, or user interactivity as per the requirement analysis. The different components of SERVIR-HKH information services are illustrated in Fig. 13.1.

13.5 GIT Solutions

The services of SERVIR-HKH are driven by the need for providing timely and right information to the right users in order to support informed decision-making. For this, the design of GIT solutions needs to consider the following key components:

- Data generation
- Data management
- Data dissemination (access and visualization)
- Application services.

13.5.1 Data Generation

The nature of services under SERVIR-HKH involves dealing with spatial data from various national and global data sets, including satellite images from different sensors and resolutions. Similarly, there are increasing data from field activities such as from forest and crop surveys, socio-economic surveys, and modelling activities which need to deal with model-specific input and output data. It is important to ensure that the data are collected and generated according to the industry standards for data consistency, quality, greater opportunity for data integration and aggregation, increased opportunities for sharing data, improved documentation and understanding of data and information resources, and data updating and security.

Various kinds of software and operational systems have been used to develop data products under different SERVIR-HKH services. The major data generation is carried out through the analysis of satellite images. In the first phase of SERVIR-HKH, the ERDAS Imagine and eCognition software were used primarily to develop data products such as land cover, glaciers and glacial lakes, and crop area. Aligning with the emerging trends, the GEE is being increasingly used in image analysis for applications such as developing the annual land cover data for the entire HKH region. Also, it is being used for big data analysis in various application areas under SERVIR-HKH.

Another set of data generation is from model runs such as SALDAS established at SERVIR-HKH. SALDAS is employed as the backbone of the Regional Drought Monitoring and Outlook System for South Asia and Agriculture Drought Watch for Nepal, Bangladesh, Pakistan, and Afghanistan. It is the implementation of the Global Land Data Assimilation System (GLDAS) developed by NASA for the South Asia region and provides, on a daily basis, the model run outputs for various drought indicator parameters such as precipitation, temperature, evapotranspiration, and soil moisture.

Similarly, HIWAT provides 48-h extreme weather predictions for lightning strikes, high-impact winds, thunderstorms, high rainfall rates, hail, and other weather events. It uses a mesoscale numerical weather prediction model and the GPM constellation of satellites. It is run during the pre-monsoon and monsoon seasons from April to September every year. The HIWAT system is implemented on SOCRATES, the HPC cluster at the SERVIR Global computing infrastructure.

13.5.2 Data Management

All the data generated under SERVIR-HKH are stored in ICIMOD's Regional Database System (RDS). The RDS is a central data repository for different thematic areas of the HKH region. A combination of ArcGIS enterprise geo-database and the Microsoft SQL Server is used to store spatial data, and the Microsoft SQL Server on its own to store non-spatial tabular data in the RDS. In addition, proper metadata is created and stored for all the data sets in GeoNetwork. GeoNetwork is an open-source metadata management system developed by the FAO. Depending upon the nature of the data, various metadata standards are used, such as the North American Profile (NAP) of the International Organization for Standardization (ISO) 19115-2003 for GIS and RS data, Global Biodiversity Information Facility (GBIF), Ecological Metadata Language (EML), Metadata profile for biodiversity data, and so on.

A backup strategy of incremental backup and a full backup plan is followed as per ICIMOD's IT guidelines to ensure safe and reliable data storage while also complying with the IT audit. Further, the Database Replica Server, a direct replica of a working database server, including both software and hardware, is implemented to ensure uninterrupted data services and to reduce the shutdown time of applications using these databases.

13.5.3 Data Dissemination

Data dissemination supports data discovery, access, exploration, visualization, and download functions. The RDS portal (https://rds.icimod.org)—a core component of the RDS—serves as ICIMOD's clearinghouse for data curation and dissemination and ensures easy access to the curated data sets which include those developed under SERVIR-HKH (Fig. 13.2). The portal provides free-text search and advanced search capabilities so that users can search by defining the title, abstract, keyword, or geographic extent. The search result would show a list of records consisting of the title, abstract, and thumbnail. The users can narrow down the search results using the provided filters and also view the detailed metadata of any record. Further, the users can download ICIMOD's published data sets after following a simple registration process. The portal offers specific tools to allow the download of temporal data (e.g. soil moisture or evapotranspiration) and climate projection data for a user-specified geographic area, time period, and other relevant parameters.

For the data which have been published as map service, the portal provides the facility to view the data as an interactive Web map using a Data Viewer application developed for the purpose.

All the data produced under SERVIR-HKH are publicly available on the RDS Portal for downloads. ICIMOD's Data Sharing Policy aligns with the philosophy of open and free access to scientific information and knowledge, and the data that are made available to the public by ICIMOD are licensed under Creative Commons Attribution (CC-BY) which allows the users to share and adapt the data as long as the creator is appropriately credited. In order to promote easier access to data on the Internet and also to facilitate proper citation, unique digital object identifiers (DOIs) are generated for the public data sets. A DOI is a persistent handle that identifies a particular data set uniquely on the internet (https://www.doi.org).

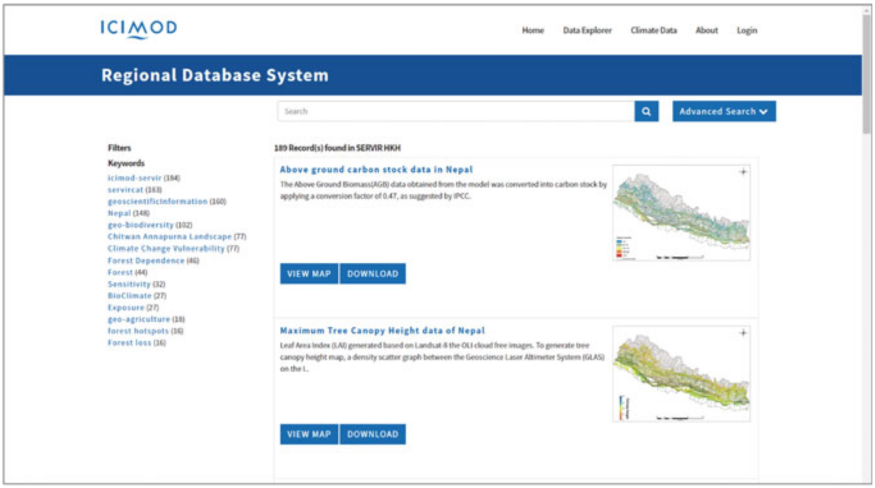


Fig. 13.2 SERVIR-HKH data on RDS

The data sets stored in the RDS can also be discovered through the Global Earth Observation System of Systems (GEOSS) GeoPortal (https://www.geoportal.org), DataCite (https://search.datacite.org), and Google Data Search (https://datasetsearch.research.google.com). And in the case of biodiversity data, they can be discovered through the Global Biodiversity Information Facility (https://www.gbif.org). Further, the data developed under SERVIR-HKH are also discoverable in the SERVIR Global Data Catalogue (https://www.servirglobal.net/#data\&maps).

13.5.4 Data and Information Portals

SERVIR-HKH has put conscious effort in transferring the developed information services to the relevant government agencies in ICIMOD's regional member countries. This helps in enhancing the sense of ownership over the information services among the agencies and also contributes to their sustainability in terms of operationalization and use. The capacity in the region varies greatly from one country to another when it comes to developing and maintaining information systems. As certain countries did not have the required IT infrastructure and technical capability in place, it was bound to be difficult to establish, implement, and maintain various applications at different agencies. SERVIR-HKH, therefore, worked towards developing a national geospatial portal that would act as a one-stop for data and information systems in those countries. Such portals serve as a platform for not only hosting data and information services developed under SERVIR-HKH, but also by different agencies in a country. This facilitates coordinated development and delivery of national geospatial services, thereby enabling improved decision-making and fostering collaboration among the various agencies in establishing effective policy for data standardization and sharing. Two portals, namely, Bhutan Geospatial Portal and Afghanistan Agriculture Information Portal, are examples of such efforts by SERVIR-HKH.

Box 1. Data and Information Portals

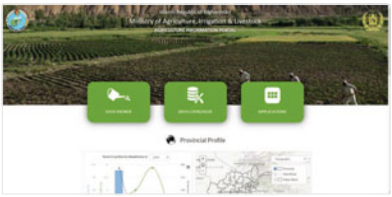
Bhutan Geospatial Portal

http://geo.gov.bt

The Bhutan Geospatial Portal has been developed jointly with Center for GIS Coordination and National Land Commission of Royal Government of Bhutan. The portal serves as a gateway to discover, access, and share geospatial data in Bhutan and allows development and hosting of interactive web based mapping applications that allow dynamic visualization and query of the data and generate information useful to various kinds of users.

Afghanistan Agriculture Information Portal

http://gis.mail.gov.af/afiims



The Afghanistan Agriculture Information Portal has been developed jointly with Ministry of Agriculture, Irrigation and Livestock, Afghanistan. The Portal facilitates the sharing of spatial and non-spatial data and allows integration of various web-based applications and provides tools to support informed decision-making in Afghanistan.

13.5.5 Application Services

The application services consist of online applications that provide query and visualization facility along with appropriate tools to generate information that is useful to decision-makers and the general public on various topics. The visualization of data in the form of maps and charts enables the users to understand the underlying issues better and helps them make informed decisions. User-friendly interfaces, along with the capability of interactive, intuitive, and innovative ways to explore and visualize data, are key aspects of the visualization component of the applications. Taking these into consideration, a number of Web mapping applications have been developed for various services of SERVIR-HKH. The individual applications can be accessed at https://servir.icimod.org/science-applications. Depending upon the features and level of complexities, the applications can be grouped into the following three categories:

- Simple visualization: The applications under this category enable simple visualization of data in the form of interactive maps (e.g. Flood Inundation Mapping, 2017).

- User interactive: Most of the applications developed under SERVIR-HKH fall into this category. The applications offer tools to query and visualize data in the form of interactive maps and charts based on user-selected parameters and geographic regions.
- Fully automated: These applications run on their own without any human intervention. They carry out tasks such as assimilation and processing of data, analysis and generation of statistics, and disseminating them through Web mapping applications in an automated manner (e.g. Nepal Forest Fire Detection and Monitoring System, Regional Drought Monitoring and Outlook System for South Asia, and Streamflow Prediction for Nepal).

As described earlier, standard Web design templates have been developed such that all the applications have a similar look and feel irrespective of the back-end and front-end technologies that have been used in developing those applications. The templates have been developed using Bootstrap, a front-end Web development framework, which ensures that the applications are responsive and are displayed well in variety of devices and screen sizes (e.g. desktop computers, tablets, etc.).

The applications consist of various common features such as map and chart sections for showing maps and charts. Likewise, a layer control section present in the application allows for the turning on/off map layers, while a tool control section lets the users to select parameters to view data and information in the form of maps or charts. Further, the applications also contain a section that provides brief information about the application and a link section that provides links to the relevant publication and to those for downloading data from ICIMOD's RDS portal. Finally, a feature to switch between English and the national language (e.g. Nepali) has been offered in a number of applications.

In addition to providing the facility to query and visualize data in the form of interactive maps through various online applications, SERVIR-HKH also allows direct access to data and map services to users with advanced technical capabilities. It also promotes the use of interoperable technologies and publishes its maps as OGC WMS services such that the users can readily integrate the data in their applications (e.g. https://bipad.gov.np). Further, SERVIR-HKH also provides the APIs used in the various applications to the partners on a request basis so that they can directly query the data in various SERVIR-HKH information systems and integrate the results in their applications.

13.5.6 Mobile Applications

The term "citizen science" was first used in 1969 and gained popularity in the 1990s (Haklay 2015). It is defined as "scientific work, for example collecting information, that is done by ordinary people without special qualifications, in order to help the work of scientists" (https://dictionary.cambridge.org/dictionary/english/citizen-science). A Web-based citizen science application was developed in the first phase of SERVIR-HKH to collect feedback on the land cover data of Nepal for 2010. The application allowed people to zoom to their familiar location or area and provide their feedback by selecting an option from a predefined list of land cover classes and also to type in their comments in the box provided. These days, mobile applications are predominantly used for field data collection as well as for getting feedback from the users.

A number of SERVIR-HKH services need field-based data either as training sample points that are required to develop data products or as data to validate and improve RS-based products. In this regard, a number of mobile applications for field data collections have been developed using Esri's Survey123 to support ongoing works of different services under SERVIR-HKH. A few of the examples of such applications include a Land Cover Survey App for Bangladesh and Nepal to collect sample points for validating the land cover data prepared in those countries under the National Land Cover Mapping System (NLCMS) and a Crop Survey App to collect various crop-related information such as on dominant winter crops, weather conditions, irrigation facilities, and cultivation status in order to support the Agriculture Drought Monitoring service in Nepal under SERVIR-HKH. The Land Cover Survey App is also planned to be used in the coming days to gather feedback from the citizens on the land cover data for the year 2019 for Nepal and Bangladesh.

Likewise, a mobile application for disseminating flood-related information has been developed jointly with Flood Forecasting and Warning Center (FFWC) of the Bangladesh Water Development Board, Bangladesh (Fig. 13.3). The application uses data from SERVIR-HKH's Streamflow Prediction along with other information products from the FFWC to provide forecast on the water levels at selected discharge stations in Bangladesh.

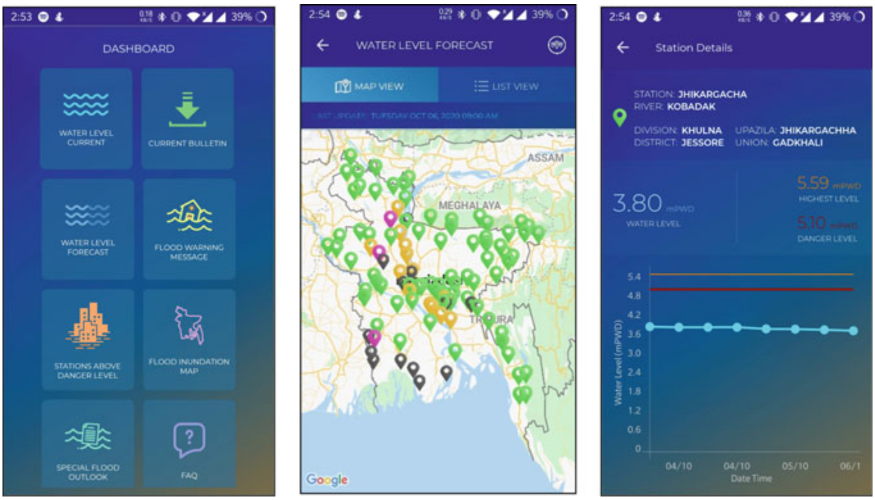


Fig. 13.3 Mobile application for disseminating flood-related information in Bangladesh

Table 13.1 Technologies and platforms used for GIT solutions at SERVIR-HKH

Functional group	Technologies and platforms	Data preparation	Data management	Data dissemination	Application services
Web-based map and data Publishing	ArcGIS Server			√	
	GeoServer			√	
	THREDDS Data Server			√	
Database management	ArcGIS Enterprise Geo-database with Microsoft SQL Server		√		
	PostGIS/ PostgreSQL		√		
Web mapping application development technologies	ArcGIS JavaScript API				√
	Open Layers				√
On-premise platforms	SALDAS	√			
	SOCRATES and HIWAT	√			
	Tethys Platform				√
Cloud-based platforms	ArcGIS Online				√
	Amazon Web Services				√
	Google App Engine				√
	Google Earth Engine	√			√
Mobile field data collection tools	Survey123 for ArcGIS	√			
	Open Data Kit	√			

The different technologies and platforms used for the purpose of data generation, management, dissemination, and application services are summarized in Table 13.1.

13.6 Experiences from SERVIR-HKH

Apart from spreading scientific knowledge, GIT plays a crucial role in developing innovative solutions using EO. GIT is a rapidly growing field where the evolution of technologies within a short span of time not only opens up new opportunities but also influences the efforts made on application development. The emergence of cloud-based platforms like GEE has enabled the development of applications to carry out big data analysis on the fly and present the results to the users quickly. There is an increasing trend of using artificial intelligence (AI) and machine learning algorithms in geospatial and EO applications. SERVIR-HKH has significantly enhanced the capacity of ICIMOD in terms of GIT infrastructure which has helped in making great strides towards implementing EO and geospatial solutions. ICIMOD has been making conscious efforts to train its human resources in these emerging fields and adopt them in various applications. This provides opportunities for executing more robust solutions that cater to the needs of the countries in the HKH region in the coming years. SERVIR-HKH has been providing regular trainings to staff from the partner institutions on the use of existing as well as emerging technologies which has helped in the co-development of applications and services. However, one of the major challenges is the limited capacity of the partners in terms of adequate GIT infrastructure; there is also the problem of frequent transfer of the staff who have been trained by SERVIR-HKH.

Regular monitoring and maintenance are necessary for the smooth operation of the applications and services. A number of fully automated systems developed by SERVIR-HKH rely on assimilation of data and on model outputs from global systems. In the event of a failure in data acquisition which happens a couple of times a year due to technical issues at the data provider's end, the operational system will not be able to generate information products.

One of the key considerations is the timely maintenance and upgrading of the hardware and software; this plays a crucial role keeping the applications operational. In some instances, the technologies used to develop applications change over time such that the existing applications need to be upgraded with the latest version of the software even during the development period. Also, certain applications need to be customized in order to add new functionalities as per requests from the partners. Further, the server hardware hosting the applications needs to be upgraded after certain years. Therefore, the provision of adequate financial as well as human resources is very important for the sustainability of the applications and services.

SERVIR-HKH has greatly benefitted from international collaborations in adopting the emerging technologies and keeping itself up to date with the global trends in the development of GIT applications. Co-development and close collaboration with AST projects have also provided the opportunity to develop the latest innovative data products and tools which are quite useful to partner agencies in their decision-making. Platforms such as SALDAS and Tethys were introduced through collaborations with the Applied Science projects. Similarly, partnerships with SERVIR-Mekong, the United States Forest Services (USFS), and Google helped in applications development using GEE. These collaborations were found to be a very useful learning process for all the institutions involved.

The main objective of SERVIR-HKH in developing applications and services is to enable the partners in using EO and geospatial information effectively. SERVIR-HKH has been making concerted efforts to ultimately transfer these applications to the partner organizations. A good understanding of the usefulness of the products and services has had a positive impact in terms of their adoption by the partners. The use of forest fire detection and monitoring system and streamflow predictions for flood early warning by national agencies in Nepal and Bangladesh are some of the examples. Further, the Bangladesh Meteorological Department (BMD) has initiated the process to establish the HIWAT system in the organization.

Our experiences show that while smart choices and use of technologies are key in designing innovative and effective applications to address the users' needs, the capacity building of partners and co-development are extremely important for adoption and sustainability of these applications and services. In this context, global networks and partnerships are indispensable to keep abreast of the latest technological advancements and to learn from each other, thereby building synergies among the GIT communities.

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Chapter 14
Strengthening the Capacity on Geospatial Information Technology and Earth Observation Applications

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14.1 Introduction

The innovative transformation in geospatial information technology (GIT) and Earth observation (EO) data provides a significant opportunity to study the Earth's environment and enables an advanced understanding of natural and anthropogenic impacts on ecosystems at the local, regional, and global levels (Thapa et al. 2015; Flores et al. 2019; Leibrand et al. 2019; Chap. 1). The major advantages of these technologies can be briefly categorized into five broad areas: multidisciplinary; innovative and emerging; providing platforms for analysis, modelling, and visualization; capability to support decision-making; and impact on policies (Shrestha and Bajracharya 2002; Revenga 2005; Thapa et al. 2014; Xia et al. 2014; Nelson et al. 2019). As such, EO can support solutions by supplying information on trends via spatiotemporal monitoring and can also assist in disaster early warning and response. On the other hand, GIT can deliver analysis and modelling of potential resource-related supply-and-demand scenarios, evaluate impacts, and provide visualization to relay information and assist the end users in decision making—all of this would contribute towards achieving the sustainable development goals (Ofori-Amoah 2008; Manfré et al. 2012; Ingole et al. 2015; Scott and Rajabifard 2017). Currently, the profound impact of EO and GIT is recognized worldwide, including in the HKH region, where it plays a significant role in monitoring, investigating, and evaluating processes such as land use and land cover change, deforestation, vegetation growth, disaster risk and damage, forest fire, and glacier dynamics in the context of climate resilience (Chap. 1). However, research in these aspects needs a more robust understanding so as to effectively implement

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_14

science-based policies and management processes. The HKH region is an extremely diverse area; it also hosts the highest mountain range in the world and is known for its highly rugged terrains that pose a daunting challenge of accessibility to collect and manage data and information. It's here the combination of GIT and EO has an important role to play—they provide access to remote regions and offer feasible ways to address critical data and information gaps.

That said, the region lacks enough professionals and trained specialists in EO and GIT (Thapa et al. 2019; Chap. 3). The progressive development of these technologies demands rapid support via building capacity through education, training, and developing more professionals and specialists. For this purpose, on the one hand, a strategic framework is required to meet the challenge of providing a well-trained workforce, and on the other, the trained professionals ought to be encouraged to apply their knowledge in various spheres. The SERVIR-HKH program (Chap. 1) is working on bridging such gaps in the region and aims to: strengthen the ability of governments and other development stakeholders to incorporate EO and GIT into the decision-making process; promote free and open information sharing through national and regional platforms and collaborations; develop innovative, user-tailored analyses, decision-support products, and trainings that advance scientific understanding; and deliver information to those who need it. Capacity building is one of the key pillars of the SERVIR program. In this chapter, we present SERVIR-HKH's capacity building approach and its implementation in the HKH region, as also its achievements and the lessons that have been learnt along the way.

14.2 Capacity Gap in the Region: A Brief Outlook

In order to successfully develop and implement capacity development activities, we need to understand the basic requirements of the national institutions and the end users so that they can utilize and apply such knowledge in the decision-making process. The emergence and advancement in technologies and their innovative applications also generate certain capacity building needs. In this regard, various consultation workshops have been organized by SERVIR-HKH in Afghanistan, Bangladesh, Nepal, and Pakistan (Chap. 3). During these consultation workshops, the participants were asked a set of guiding questions on data, capacity, and services related to their countries. The feedback from the groups were summarized, assessed, and ranked on a priority basis. The basic priorities, requirements, and gaps were identified in terms of: data and knowledge; capacity gap and gender disparity; and lack of institutional and technical capacities. The data and knowledge gaps generally pointed to the lack of human resources, geospatial capacity, infrastructure, and data availability. The capacity gap in terms of EO and GIT in the HKH is large due to the lack of an appropriate strategy to sustain long-term projects; this leads to challenges in maintaining and improving the infrastructure, updating geospatial data, and in strengthening human resources after the completion of projects (Thapa et al. 2019). In addition, the involvement and participation of women in the EO and GIT fields is rather low in the region (Tripathi and Thapa 2019) although the significant role of gender and gender-responsive policy agendas and decisions is well recognized (Chap. 15).

The assessment of the institutions across the countries in the region showed varying degrees of geospatial capacities in terms of GIT infrastructure and human resources. The needs also varied. For instance, most of the institutions in Bangladesh indicated that they needed hydroclimatic data more frequently to develop an early warning system for riverine floods, flash floods, abnormal water surges in the coastal areas, and to assess related vulnerabilities such as riverbank erosion, crop loss, and landslides; while institutions in Nepal mentioned that they needed data based on elevation as there were several variables in terms of land and climate; the Afghanistan institutions stated that their agencies mostly used annual data to produce geospatial products for irrigation planning and for assessing the impacts of hazards such as droughts, floods, and landslides. The data requirements may also be of daily, seasonal, or annual in nature to perform various types of spatial analysis and to produce map products and services. As mentioned earlier, many institutions in the region are lacking strategies for the sustainability of GIT projects, as the majority of geospatial applications are project-based, thereby creating challenges for upgrading GIT infrastructure and updating geospatial data and enhancing the skills of human resources after the completion of projects. There is also a knowledge gap in terms of EO and GIT applications at the decision- and policymaking levels, apart from the issue of poor data-sharing provisions among the institutions. For instance, Pakistan's capacity and infrastructure in geospatial technologies are fairly good, but there are lack of platforms available for the sharing of data and products beyond products a single institution. Overall, in the HKH region, there is a need to build geospatial capacities (infrastructural as well as by way of human resources). Therefore, strategic and systemic capacity building pathways for individuals and institutions in the region are a prerequisite.

14.3 Capacity Building Pathways

The key capacity development dimensions have been identified at three levels: individual capacity—this deals with changing attitudes and behaviors by imparting knowledge and skills via training; Institutional capacity—this focuses on overall performance and operational proficiency (i.e., by way of developing instructions, tools, guidelines, and an information management system) to assist and catalyze organizational changes; and systemic—this enables the creation of a conducive environment and assists in effectively reflecting the capacity in decision-making, i.e., in terms of policy, economy, and accountability (Shrestha and Bajracharya 2002; GEF 2003; Potter and Brough 2004; UNDP 2008; Chandler and Kennedy 2015). Here it must be emphasized that the process of building capacity is iterative, involving design, application, knowledge, and modification. Thus, based on a

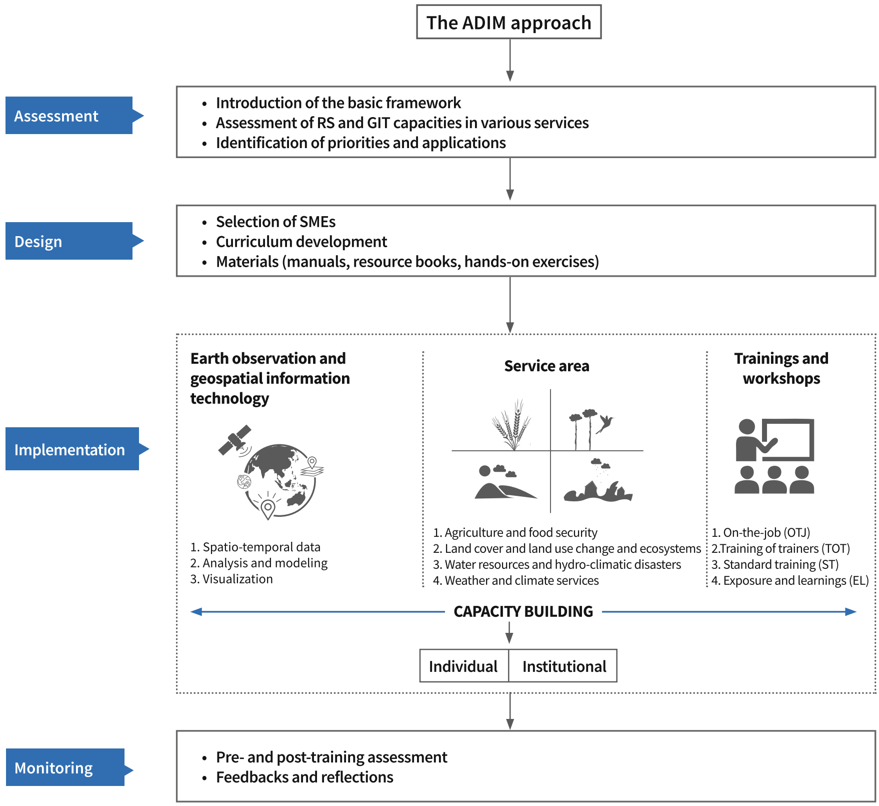

Fig. 14.1 Capacity building framework within SERVIR-HKH

situational analysis of the HKH region and acknowledging the lessons that were learnt, the ADIM approach was developed, which addresses Assessment, Design, Implementation, and Monitoring (Thapa et al. 2019). This is briefly presented in Fig. 14.1.

14.3.1 Capacity Assessment

As capacity needs differ among various institutions at the regional and national levels, it is essential to assess the existing capacity and future needs to determine the priorities at various levels in order to design effective plans. It can be characterized as analyzing the preferred capacity compared to the existing one and offering systematic methods to gather critical information and data on the capacity resources and needs. This is the pillar of any capacity development formulation that addresses the demands and needs to strengthen and optimize the existing capacity; it therefore incorporates such steps as mobilization and design, conduct and summarization, and then interprets the assessment results. So, various country consultation workshops were organized along these lines during the years 2015 and 2016 in Afghanistan, Pakistan, Bangladesh, and Nepal. These workshops helped in the systematic assessment of gaps, needs and priorities, as well as evaluated the capacities of each country (Chap. 3). These gaps and needs were subsequently grouped into the four major thematic areas of SERVIR: agriculture and food security (AFS); land use, land cover, and ecosystems (LULC&E); water resources and hydro-climatic disasters (WRHD); and weather and climate services (WCS). This assessment process played a significant role in promoting active user engagement, ongoing partnerships, and in identifying more engagements and partners; it also served as an input for our capacity development pathways.

14.3.2 Capacity Building Design

The appropriate designing of capacity building interventions is crucial during the formulation phase. The emphasis here is on strategic thinking based on innovations to ensure that the implementation methodology is more progressive and effective with an adaptive vision to utilize emerging technologies such as SAR, GEE, machine learning, cloud computing, and open access tools. After the assessment process, the key design considerations involve priority issues, key opportunities, sequenced activities, and a realistic selection of activities. For this purpose, consultations were held with the subject matter experts (SMEs) and the priority issues were selected as part of the implementation aspect. Four major types of capacity building activities were identified which would enhance the individual, institutional, and systemic capacities at national and regional levels: on-the-job training (OJT); standard training (ST); training of trainers (ToT); and exposure and learning (EL). The OJT and ToT exercises were considered as institutional capacity building activities, while the other two were seen as individual capacity building activities (Thapa et al. 2019).

The OJT activities were semi-structured, focusing on enhancing the capacity of partner institutions to develop, operate, and maintain specific applications and services. They had been designed keeping in mind the background knowledge and skills of the participants who then worked with the SMEs on a rotational basis and learnt how to carry out certain tasks. Upon completion of the training (a period of one to two weeks), the participants were assigned to work independently on the target applications that needed to be completed in a certain time period. The ToTs were focused on training the teaching staff and were aimed at institutional capacity building in order to reach out to more participants via academic institutions. This training lay emphasis on content, skills, knowledge, and effective communication and presentation skills; it also got the participants to develop exercises and refine the materials with local data. The ST module focused on general GIT and EO perspectives and their applications on specific subjects; this module saw the participation of professionals from diverse fields. The EL segment imparted awareness on recent developments and applications in GIT and EO and also explained the benefits and prospects of these technologies. All these short-term trainings were primarily targeted at career-seeking youngsters and senior managers for exposure; they were thus exposed to academic and technical exchanges during professional conferences, workshops, and competitions. SERVIR-HKH also worked closely with the thematic SMEs to design a curriculum that incorporated aspects such as learning objectives, expected outcomes, target audience, and daily agenda. Besides, the development of various theoretical and practical materials, including training modules, manuals, reading materials, hands-on exercises, and PPTs, were part of this phase.

14.3.3 Implementing Capacity Building Activities

This phase of the ADIM approach refers to the execution of the capacity building activities wherein the four modules of ToT, OJT, ST, and EL were offered to the participants. They were then divided into three categories: policymakers/decision makers; technical professionals; and youth. The policymakers and decision makers formed the top level of the hierarchy; they represented leadership and were the ones who could influence the capacity of GIT and EO services in partner institutions. The technical professionals represented the middle level of the hierarchy and would be mostly involved in the development of databases and in the application of GIT and EO in different thematic areas; so, they were the one who would prepare the products to be used by the leaders. The youth, while representing the lower level of the hierarchy, were nevertheless accorded high importance since they were the ones who needed to be aware and convinced of the recent technology; they were the ones who would be able to forge networks during climate emergencies (Thapa et al. 2019).

Meanwhile, various national- and regional-level collaborative activities took place in capacity building in partnership with local institutions of partner countries and the private sector. In line with ICIMOD's Midterm Action Plan-IV (MTAP-IV) for 2018–2022, SERVIR-HKH has been aiming to overcome the persistent gender inequalities in all sectors by identifying these inequalities and the gaps in addressing them; it has been proactive in redressing the discriminatory social and gender norms and has also been tackling the practices, attitudes, and power relations that help in the prevalence of such norms. (A more elaborate account of SERVIR-HKH's gender-inclusion strategies is discussed in Chap. 15.) In a nutshell, in terms of capacity building, ICIMOD has been focusing on the following areas: providing training on the methods and tools for gender-disaggregated data collection and analysis; enhancing the tools of gender analysis; building women's leadership by proactively including them in equal numbers in trainings, workshops; encouraging young women professionals and students to take to this discipline; fostering "gender champions" in SERVIR-HKH; and collaboratively developing and testing services with the targeted groups.

14.3.4 Monitoring and Evaluating the Impact of Capacity Building Activities

Fundamentally, monitoring and evaluation (M&E) is the measurement that helps to interpret the performance of capacity building approaches; it takes into consideration such aspects as design, implementation, learning, performance, and the impact of capacity building pathways. And while monitoring implies an ongoing measurement, evaluation is a periodic measurement (Ortiz and Taylor 2009; Chap. 18). In the area of capacity building and its effectiveness, M&E gives priority to the following two points: clarity of purpose, i.e., for what, why, and for whom; the nature of the information that is required and choose the way in which data have to be collected—for example, by way of a well-conceived and targeted survey questionnaire. The M&E process pays attention to both short- and long-term indicators; while the short-term indicators give insights into specific actions and steps and show whether a particular capacity building effort has worked or not, the long-term ones seek to describe the results of a particular capacity building activity over a period of time.

Long-term monitoring under the SERVIR-HKH program follows the Planning, Monitoring, Evaluation, and Learning (PMEL) framework based on the Theory of Change (ToC) and Participatory Impact Pathway Analysis (PIPA) (Chap. 18). As for short-term monitoring, it looks at the capacity that has already been built; here, pre- and post-assessment surveys are conducted for each activity (excluding exposure and learning) in order to gauge the participant's expectations, skills, and knowledge, and also to get their feedback on improving the approach. For this purpose, pre- and post-training evaluation surveys were conducted so as to know whether the participants had improved their knowledge and skills in the subject matter. The surveys were composed of three different sections: basic information and expectations from the participants (pre-assessment) and the relevance of the training for different topics (post-assessment); the incorporation of scientific knowledge—this related to self-assessment of the basic knowledge on the subject and assessing the technical skills related to the subject; and feedback and reflection, wherein the responses were mapped via four levels of knowledge and skills —"Low/No", "Basic", "Intermediate/Relatively High", and "Advanced/High".

14.4 Mapping the Impact Pathways

Mapping the impact of capacity building activities is a key indicator of successful implementation; it provides a means to map the direct and indirect cause-and-effect linkages. Figure 14.2 presents the impact pathway of the ADIM approach and shows significant capacity development in the HKH region. This is briefly discussed below.

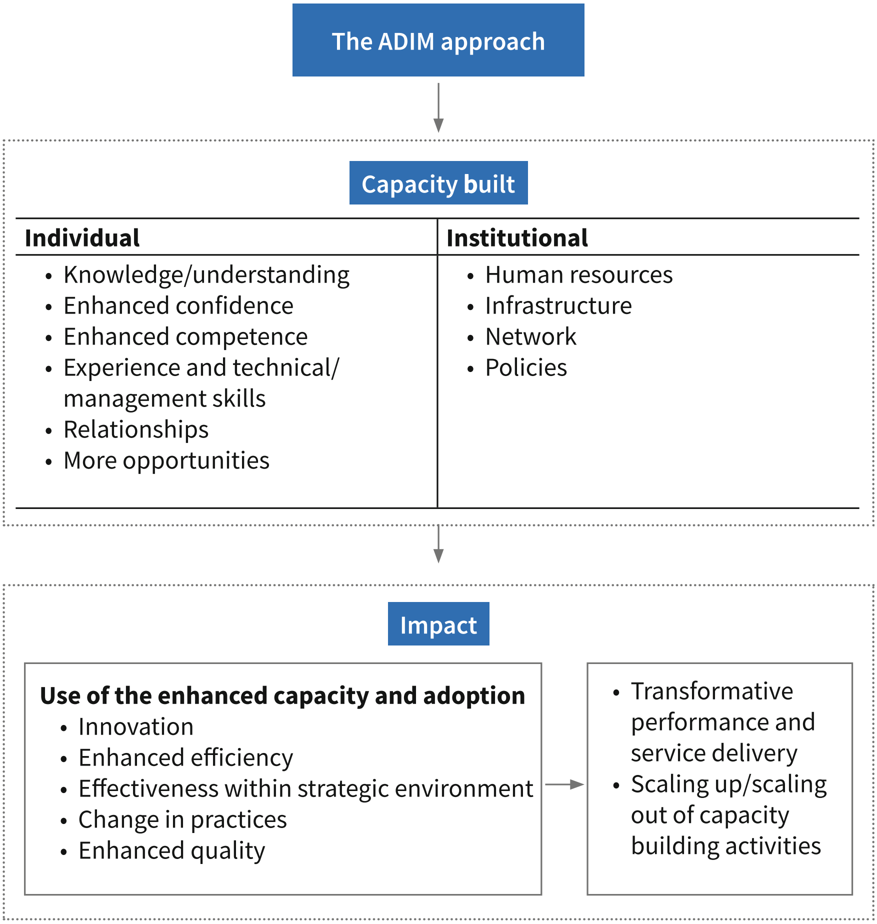

Fig. 14.2 The capacity building impact framework

14.4.1 Training Modules, Contents and Materials

Based on the needs assessment and country consultation workshops, an elaborate development of the capacity building modules under the four thematic areas was carried out (Table 14.1). In addition to these four thematic areas, the common needs and priorities of all the countries were captured under a crosscutting theme. In SERVIR-HKH Phase II, all the topics under the thematic areas were secured within 27 distinct modules and were used to deliver capacity building training during the years 2016, 2017, 2018, and 2019. These modules covered theoretical and hands-on knowledge on subjects such as climate data analysis, land use, land cover, crops, glacier mapping and monitoring, hydrological modelling, advanced RS and GIT applications, and WebGIS application development. Overall, five modules were designed under AFS themes, serving two for OJT and three for ST; twelve modules were designed under WRHD and LULC&E themes, including one each for OJT and ToT respectively. The WCS themes consisted of only one module owing to a single service (i.e., SALDAS), while the crosscutting themes incorporated nine distinct modules serving six for ST, one each for OJT and ToT, and two for exposure and learning activities.

14.4.2 Strengthening Institutional and Individual Capacity

During the past four years, SERVIR-HKH has organized 62 capacity building events in the HKH region (Table 14.2). Overall, 1354 participants benefited from these activities, including professionals, policymakers, decision makers, and youth, representing 290 distinct institutions in the region and beyond. The participants represented various government ministries, organizations, institutions, local departments and offices, research centers, academic institutions, the private sector, and INGOs and NGOs. The breakdown of the events goes thus: one in 2016; 19 each in 2017 and 2018; and 23 in 2019. Among them, five each were under TOT and OJT; eight under the exposure and learning segment; and 44 under ST. Although the number of OJT and ToT events were less during the four years, yet they were effective in strengthening the institutional capacity of the partner organizations as these were targeted at specific applications for setting up self-managed information systems to meet organizational requirements. The OJTs were focused on professionals of partner institutions from Bangladesh, Afghanistan, and Nepal; and these trainings dealt with glacial lake mapping, drought mapping and monitoring, and WebGIS development. As for the ToTs, they helped to enable the trainers to conduct independent courses and transfer the knowledge to a wider audience.

The SERVIR program has successfully trained professionals and faculties from various institutions in three countries: Nepal's Agriculture and Forestry University, Kathmandu University, Tribhuvan University, and Pokhara University; Afghanistan's Kabul University; and Bangladesh's Jahangirnagar University. The broad topics and theories that were covered included advancement in the applications of GIT and EO in water resource management, the application of SAR, and big data analysis using GEE. At present, the OJT and TOT segments are serving as the core part of the capacity development activities in the region which are to be taken forward and replicated by the partners and professionals in the respective countries. For example, Kabul University, independently and in collaboration, has organized nearly 10 trainings on the topics of land cover mapping and monitoring, and water resource management (Box 14.1), while the Pashchimanchal Campus of Tribhuvan University organized a training in 2019 on SAR and GEE for the graduating students. Similarly, Jahangirnagar University organized a training in GEE in Dhaka in 2019.

Table 14.1 The development of theme-based capacity building materials (2016–2019)

S/N	Module subject	Theme	CB type	Material
1.	Climate data analysis for drought monitoring	AFS	ST	PPT, manual, hands-on tutorials
2.	Agriculture information system (irrigation portal)	AFS	ST	PPT, hands-on tutorials
3.	WebGIS application development	AFS	OJT	PPT, hands-on tutorials
4.	Crop mapping	AFS	OJT	PPT, hands-on tutorials
5.	FEWS NET for agro-climatological analysis	AFS	ST	PPT, hands-on tutorials
6.	Hydrological modeling	WRHD	ST	PPT, manual, hands-on tutorials
7.	Mapping and monitoring of glaciers	WRHD	ST, OJT	PPT, manual, hands-on tutorials
8.	VIC modeling	WRHD	ST	PPT, hands-on tutorials
9.	RS and GIS for water resource management	WRHD	ST, ToT	PPT, manual, hands-on tutorials
10.	RS of snow water resources	WRHD	ST	PPT, hands-on tutorials
11.	Streamflow forecasting tools	WRHD	ST	PPT, hands-on tutorials
12.	Ecosystem services using the ARIES platform	LULC&E	ST	PPT, hands-on tutorials
13.	Land cover and land use mapping	LULC&E	ST, ToT	PPT, manual, hands-on tutorials
14.	MRV-REDDcompass	LULC&E	ST	PPT, hands-on tutorials
15.	Tree cover estimation	LULC&E	OJT	PPT, hands-on tutorials
16.	SAR for forest monitoring	LULC&E	ST	PPT, book, hands-on tutorials
17.	Land cover monitoring system	LULC&E	ST	PPT, hands-on tutorials
18.	SALDAS	WCS	ST	PPT, hands-on tutorials
19.	SRTM-2 DEM applications	CC	ST	PPT, hands-on tutorials
20.	Sentinel satellite data analysis	CC	ST	PPT, hands-on tutorials
21.	GIS application development	CC	OJT	PPT, hands-on tutorials
22.	Google Earth Engine	CC	ST, ToT	PPT, hands-on tutorials
23.	Empowering women in GIT	CC	ST	PPT, hands-on tutorials
24.	Agriculture and disaster monitoring in the HKH (AOGEOSS)	CC	ST	PPT, manual, hands-on tutorials
25.	GWF, GFOI	CC	EL	PPT
26.	NASA SpaceApp, Miss Tech	CC	EL	R&D prototype demo
27.	Connecting space to village	CC	ST	PPT, hands-on tutorials

Table 14.2 Institutional and individual capacity building (2016–2019)

Fiscal year	Event type	No. of events	Male (%)	Female (%)	Total
2016	ST	1	63.63	36.36	22
2017	OJT	1	83.33	16.67	6
	ToT	1	100.00	0.00	4
	ST	13	74.82	25.18	278
	EL	4	54.05	45.95	185
Total		19	67.02	32.98	473
2018	OJT	3	90.00	10.00	10
	ToT	1	75.00	25.00	8
	ST	14	60.88	39.12	478
	EL	1	90.00	10.00	10
Total		19	62.25	37.75	506
2019	OJT	1	100.00	0	6
	ToT	3	83.33	16.67	36
	ST	16	72.44	27.56	283
	EL	3	78.57	21.43	28
Total		23	74.22	25.50	353
Overall		**62**	**67.13**	**32.87**	**1,354**

ST Standard training; *OJT* On-the-job training; *TOT* Training of trainers; *EL* Exposure and learning

The analysis shows variations in the participation of men and women—67% men and 33% women. And in terms of women's representation in the years 2016, 2017, 2018, and 2019, the statistics show percentages of 36, 33, 38, and 26, respectively. The significant increase by 5% in 2018, as compared to 2017, demonstrates the successful integration of ICIMOD's gender strategy into SERVIR-HKH's action plan (ICIMOD 2017). In contrast, there was a significant decline, by 12%, during 2019, as compared to 2018; this could be attributed to various factors, including the postponement of some women-focused activities to be held in Afghanistan in 2019. Also, the fact remains that there are fewer women professionals working in the GIT sector in the HKH region.

14.4.3 Strengthening Service Area Capacity

Under the various service areas (Fig. 14.3), the highest number (21) of events were organized under the crosscutting areas; these served 618 individuals and saw the participation of 210 institutions. Among the four thematic service areas, the WRHD segment organized 16 capacity strengthening events and served 321 participants from 36 institutions. As for the LULC&E and AFS service areas, they served 60 and 43 institutions, respectively; while the LULC&E segment provided various

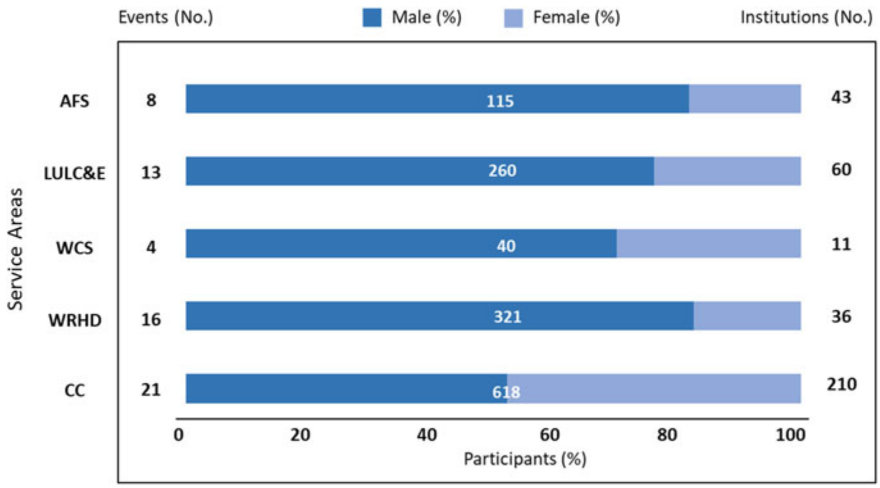

Fig. 14.3 Service area-based capacity building events. Note: The number displayed over each bar depicts total number participants

trainings to 260 individuals, the AFS segment catered to 115 individuals. The lowest number of activities was recorded by the WCS service, which tended to 11 institutions and their 40 professionals. Among the participants, the gender gap was found to be wider in the AFS and WRHD (<20% of female participants) segments as compared to the LULC&E and WCS service areas; this was despite several efforts and measures being taken to bring in more women participants to the training programs. Here, it has to be noted that the participants in these service areas were selected based on institutional nominations and that these institutions have less women professionals working in them. Interestingly, the crosscutting areas had the best gender balance, with the participation rate of women at 48%; this might have been because some of the events in the crosscutting areas were open to all who met the minimum criterion and they did not require nominations.

14.4.4 Capacity Building Outreach to Institutions and Country

Although the major capacity building events were focused on Afghanistan, Bangladesh, Nepal, and Pakistan under the SERVIR-HKH program, the other four regional member countries of ICIMOD (Myanmar, Bhutan, China, and India) and 20 other countries also benefited from the capacity building activities (Table 14.3). Out of the total 62 events, Nepal participated in 36, followed by Afghanistan in 28, Bangladesh in 19, Pakistan in 11, Bhutan in nine, and India and Myanmar in eight each. Other countries, too, participated significantly in 16 events, sending 76

Table 14.3 Country-wise participation in capacity building activities

Country	Events	Institutions	Male (%)	Female (%)	Total
Afghanistan	28	26	88.78	11.22	392
Bangladesh	19	52	73.29	26.70	161
Bhutan	9	6	76.47	23.52	17
China	2	3	60	40.00	5
India	8	10	64.71	35.29	17
Myanmar	8	18	58.14	41.86	43
Nepal	36	130	52.11	47.89	616
Pakistan	11	17	77.78	22.22	27
Others	16	39	63.16	36.84	76

[a]Others include: Australia, Brazil, Canada, Germany, Finland, France, Gabon, United Kingdom, Guatemala, Italy, Kenya, Cambodia, Mongolia, Malawi, Mozambique, Netherlands, Papua New Guinea, Thailand, United States, and Vietnam

participants from 39 institutions. As for the overall participation count, country-wise, Nepal registered the highest number, with 616 people from 130 institutions. This high rate of participation has to do with the fact that Nepal hosted more events than any other country. Afghanistan was second, with 392 participants from 26 institutions. As for Bangladesh, it took part in 19 events, sending 161 participants from 52 institutions, the second highest by way of institutional representation. In terms of gender balance, Nepal again captured the first place, with over 48% of the representation from women. This has largely to do with women-focused events like “Miss Tech” and “Empowering Women in Geospatial Information Technology” (ICIMOD 2018, 2019a) which have greatly encouraged women to be more active participants in the whole technological enterprise. As regards other countries in terms of female representation, Myanmar, China, and India registered over 35% participation, while Bangladesh, Bhutan, and Pakistan recorded a participation level that was below 30%. Afghanistan stood last in the gender balance list, with only 11% of its representatives being women. This has to do with the fact that less number of Afghan women are engaged in the GIT sector and there’s also a reluctance to travel due to certain social norms.

The agile development of GIT and EO technologies demands continuous and sustainable capacity building activities; this, in turn, requires higher educational institutions to be the focus of capacity building efforts wherein they also become knowledge-sharing platforms. So, there is an imperative need to strengthen the capacity of the universities to facilitate research in these areas and to provide training. Realizing such needs, SERVIR-HKH has collaborated with partner universities and supported curriculum development in geoinformation science for running bachelor’s and master’s programs. It has helped in the introduction of master’s programs in GIS and Remote Sensing, in Nepal Open University, Tribhuvan University, and Jahangirnagar University. Besides, it is supporting Kabul University in developing a bachelor’s program in GIS.

14.4.5 Focus on Women and Underprivileged Communities

Despite the profound infiltration of GIT and EO in its planning and decision-making processes, the concepts are still rudimentary or nonexistent in school education across the HKH region. A lack of skilled human resources and institutional capacities and gaps in communication hinder schoolteachers from introducing these concepts and their applications to students. In this regard, in 2019, SERVIR-HKH introduced a novel capacity building program called "Connecting Space to Village" to address the needs of the village communities. Under this theme, it organized a teachers' training program in 2019 which focused on imparting GIT knowledge to the local communities. This event brought together 19 high-schoolteachers from nine schools located in different parts of Nepal; the specific aim was to train these teachers on the use of SERVIR-HKH EO and GIT application services and data so that they could transfer this knowledge to school students and the local communities.

As regards having a gender-balanced workforce in the region, SERVIR-HKH has initiated a specially designed capacity building program for targeted groups of young and early career women of Nepal. This program was held in 2018 and 2019 and brought together young women from different backgrounds. These events saw theoretical and hands-on exercises on the use of EO and GIT which covered a range of topics, including the four thematic service areas of SERVIR. The replication of this initiative is now being sought by Bangladesh, Afghanistan, and Pakistan. And, as previously mentioned, ICIMOD also supported the holding of "Miss Tech 2017" in Kathmandu, a major national competition aimed at promoting techno-entrepreneurship among women; the theme of this particular event was "Transformational Changes through Technology". Such initiatives have not only helped women in starting and navigating their geospatial careers but also geared them towards providing leadership in the field of GIT.

14.4.6 Monitoring and Evaluation of Capacity Building Activities

For the evaluation of the capacity building activities, we targeted short-term monitoring to assess the knowledge gained by the participants; it also evaluated the success and shortcomings of the implementation procedure. This gave a broad picture about the experience of the participants. An evaluation response case as an example is presented here from a training on "Introductory Course on Synthetic Aperture Radar", which aimed to provide theoretical and practical knowledge on SAR data and its applications for crop monitoring in Afghanistan. The training, delivered by two resource persons from ICIMOD, was attended by 10 professionals from three institutions in Afghanistan. This seven-day training covered the following aspects: image formation; polarimetric SAR; backscattering mechanisms;

Table 14.4 Responses (in %) of the participants on the quality (an example from the training on SAR)

S/N	Relevance	Extremely high	High	Medium	Low	Not at all
1	The presentation was clear and to the point	60	30	10	0	0
2	The training was interactive	60	40	0	0	0
3	The presenter(s)/facilitator(s) were highly knowledgeable about the subject matter	70	30	0	0	0
4	The training achieved its goals and objectives	50	40	10	0	0
5	The materials/handouts were useful	40	50	10	0	0
6	The presentations were interesting and practical	50	40	10	0	0
7	Adequate time was provided for attendee questions	40	40	20	0	0
8	The content was well organized and easy to follow	40	40	20	0	0
9	The training met my expectations	20	60	20	0	0
10	Appreciation of the coffee break and lunch	70	30	0	0	0

sensitivity of radar signals to moisture; radiometric and geometric distortions; processing of SAR data; and various applications of SAR data (ICIMOD 2019b). Table 14.4 presents the overall response of the participants.

As can be seen from Table 14.4, on several parameters, 90% of the participants described the relevance of the training as “extremely high” and “high”; this reflects the success of the whole program. And as to whether the participants had increased their capacity, skill, knowledge, and application ability, the response was cent per cent positive (Fig. 14.4a). The sessions on self-assessment and technical skills also showed positive results as we could see that the participants had indeed been able to learn significantly from them. During the pre-evaluation stage before the self-assessment session, 7% of the participants had stated that they possessed advanced knowledge, 21% had described their knowledge as “intermediate”, 31% had described it as “basic”, while 40 had acknowledged that they possessed no knowledge at all in the area. However, these percentages improved significantly after the training program as 21% of the trainees stated that their knowledge and skills had reached an advanced stage, while 31% of them described their knowledge level as “intermediate”.

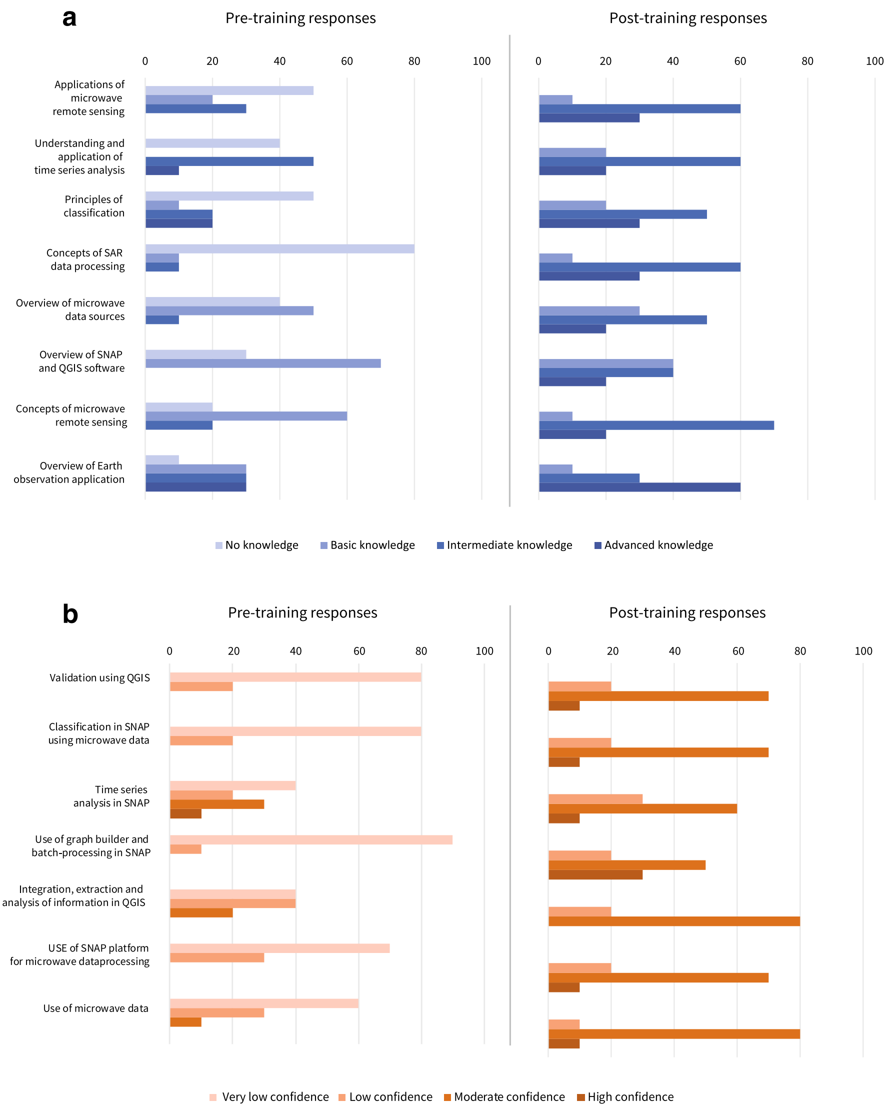

Fig. 14.4 **a** Depiction of pre- and post-training responses of participants on various themes under the self-assessment category. **b** Depiction of pre- and post-training responses of the participants on various themes under the technical skills category

As regards the technical skills segment of the training, before the program, only 1% of the participants had described their confidence level as "high", 8% had said they were "relatively confident", 28% had stated they possessed basic skills, while 65% had acknowledged that they had no skills at all (Fig. 14.4b). But the post-training evaluation reflected a positive leap in these figures, with 10% of the trainees saying that their confidence level was high, while 60% stated that their confidence level had improved. More remarkably, approximately 65% of the participants who had come to the training without any skills stated that after the training, they had acquired basic knowledge and that their confidence level was better.

Adopting Capacity Building

Transferring knowledge is the key part of any capacity development activity that helps the target group achieve short- and long-term goals. In this context, SERVIR-HKH provides various trainings to bridge the capacity gaps in the GIT and EO fields. The success of these trainings can be observed by the adoption and implementation of capacity building activities by partner institutions, professionals, and faculties.

A. Training on land use/land cover mapping using remote sensing and GIS

This five-day training programme, held in Kabul University, brought together 23 students from three faculties – of geoscience, environmental science, and agriculture – of Kabul University. The training mainly focused on the use of EO and GIT applications for land cover mapping in Afghanistan and covered basic concepts of land use and land cover (LULC) mapping, remote sensing, image classification, land cover classification, and applications of land cover mapping.

B. Training workshop on Earth observation and geospatial technologies for water resources management in Afghanistan

This was a 10-day event that brought together 38 lecturers from Nangarhar, Laghman, and Kunar universities of Afghanistan. They represented the faculties of agriculture, engineering, computer science, geology, and geography. The training covered basic concepts of water resource management, theoretical and practical understanding of RS and GIS applications in watershed and drainage delineations, generation of meteorological data, and hydrological modeling.

Box 14.1. A snapshot of institutional capacity building activities in Afghanistan

14.5 Challenges and Opportunities

In this chapter, we have presented the approach that has been adopted for building the capacity of individuals and organizations in EO and GIT applications in the HKH region; we have mentioned that, over the last four years, we conducted 62 events successfully in this area of capacity building. Some institutional success stories, such as establishing a GIS Lab, preparing a glacier data inventory, and many more are documented in http://servir.icimod.org/stories. However, there are several challenges ahead; there are also several opportunities that are waiting to be tapped (Table 14.5).

Table 14.5 Key challenges and opportunities

Challenges	Opportunities
Collaboration with stakeholders	
• Bringing key stakeholders to country consultations and prioritizing capacity needs • Getting policy-level personnel to provide wider inputs on gaps and needs	• Bringing stakeholders closer and engaging in the assessment of capacity building gaps and needs • Preparing a priority list to design activities and implementation
Emerging EO and GIT techniques	
• Frequent updating of the capacity of individuals and institutions • New curriculum, materials, and programs on capacity building • Resource stress and lack of availability of appropriate SMEs	• Cost-effective choices on: – Training material development and implementing capacity building activities – Availability of open-access tools and data for individuals and institutions • Acquiring cutting-edge expert knowledge by engaging SMEs
Capacity building events	
• Irrelevant nominations for highly technical trainings • Difficulties in ensuring gender balance • Geopolitical tension among the regional member countries	• Enabling a variety of people—from youth to professionals and technicians—to set policy agendas for the larger benefit of society Multiplying the effects of learning, adding value to knowledge, and instilling a greater sense of ownership among the stakeholders
Women's participation	
• Less women professionals in the EO GIT fields • Social and religious obligations hindering women's participation	• Designing women-focused capacity building programs • Nurturing a gender-balanced workforce
Monitoring and evaluation	
Participants' reluctance to provide true responses and a lack of motivation to respond to survey questionnaires	• Understanding the expectations and learning from the achievements • Tracing the impact of an activity and taking the necessary measures to improve it
Sustainability	
• Staff turnover at partner institutions • Problem in the continuation of services and plans because of the finite nature of projects	• Ensuring an overlap between outgoing and incoming staff, and transferring knowledge to retain capacity • Conducting periodic refresher trainings to bring the new staff up to the mark • Engaging with the senior management to promote the utilization of the new knowledge for decision-making
Others	
• Language barrier • Retaining professionals for long term	• Interacting with people from diverse social backgrounds • Forging stronger partnerships and professional networks

Adopting online virtual capacity building in SERVIR-HKH

The COVID-19 pandemic has seen SERVIR-HKH adopting online learning methods and strengthening the capacity in this area. The online platforms that have been used are: Microsoft Teams, Zoom, AWS Cloud, and edX. In this regard, SERVIR-HKH organized a training programme on "Empowering Women in GIT", from 19–22 May 2020. Twenty-five women from across Nepal and Australia attended the training for four days with a singular focus – to expand their knowledge and skills in GIT. The programme involved women-focused training events to help women students and professionals make a career in the GIT field. The training was conducted remotely via the Microsoft Teams platform. The presentations, resource materials, and session recordings were made available via Microsoft Teams so that the participants could refer to them and strengthen their knowledge base.

Box 14.2. Adoption of online capacity building activities

14.6 Conclusion and Way Forward

Increasing the influence and potential of EO data and GIT for making geographically informed decisions in resource planning has been a much sought-after goal in the HKH region. The rapid developments and new paradigms on EO and GIT applications, the lack of skilled human resources and institutional capacities in the region demand robust capacity building activities to reap the benefits of these applications. This chapter has presented in detail the ADIM—assessment, design, implementation, and monitoring—framework adopted by SERVIR-HKH in strengthening capacity enhancing activities. Through this approach, we have been able to identify the gaps and needs, design efficient capacity building programs, implement plans to achieve lasting impacts, and monitor the results. In this regard, we have not only engaged with subject matter experts but also decision makers for the efficient application of these frontier technologies. We have also given priority to gender equity. While the challenges have been aplenty, our programs such as ToT, OJT, ST, and EL have played an instrumental and significant role in strengthening the capacities of individuals from all levels as well as institutions and organizations on the use of these emerging technologies. We have also integrated the M&E approach to gather regular feedback, thereby improving the overall quality of the capacity building ventures. We believe that by sharing our experiences, we are widening the knowledge pool for the capacity building practitioners in the HKH region and beyond. However, there is a lot more that needs to be done in this vital area of capacity building. In the upcoming years, the following areas could be looked at:

- Applying uniform formats for training manuals and materials among the service areas;
- Conducting virtual trainings and organizing distance learning capacity building events through digital platforms such as Microsoft Teams, Zoom. AWS Cloud, and edX;

- Developing a web portal with self-learning training materials which will not only help enhance the capacities in the region but also beyond;
- Prioritizing the use of open-source GIS/RS software; and
- Conducting regular organizational capacity assessments and tracer surveys to monitor the impacts of the capacity building efforts and to identify the emerging needs in the region.

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Chapter 15 Gender Integration in Earth Observation and Geo-information Technology Applications: Correlation and Connections

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15.1 Introduction

As technological innovation and advancement is sweeping across the world, transforming economies, countries, and societies, Earth observation (EO) and geo-information technologies (GIT) have come closer to the public realm and become exceedingly an all-encompassing part in the daily lives of people, with more uses and users. These technologies today are not just "research and visualization tools", but they touch upon all aspects of people's lives, bringing in advantages as well as challenges for different groups of people (McLafferty 2005:38). These technologies and applications present opportunities for people to get information, to connect to one another, to explore and link to new markets and new areas of resource pools which could lead to innovations, increase efficiency and productivity, and also help in the delivery of effective public services (World Bank 2019). These technologies and applications can also be used by people, institutions, and corporations to exercise power over others, and it could influence gendered social relations and spaces in all spheres—social, economic, and political (McLafferty 2005; Stephens 2013). Thus, EO and GIT have significant implications for social and economic development, as well as for human rights and gender and social equality as they "can be engines of economic growth, offering new possibilities in health care, education, communication and productivity"—for example, a case of health, with the application of EO and GIT, can be built on geospatial data to track virus spread, identify vulnerabilities, manage facilities, and target responses

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_15

(United Nations 2020:2). Therefore, geospatial information is the foundation for various social and economic development activities, apart from its commercial uses (Ibid).

Technologies are set in the dynamics of the prevalent gender, social, and economic relations, which influence how the technologies are developed and how, where, and by whom they are used (McLafferty 2005). The prevalent unequal power relations between women and men from different socioeconomic backgrounds are bound to influence the development of, access to, and control over these technologies as well as the impacts they will have on them. Therefore, it is critical to expand our view and consider how these technologies are connected with the everyday lives of women and men in the society, given their position, status, and location. This means that it is crucial to explore and examine the correlations and connections between gender and EO and GIT.

This chapter seeks to explore the connections between gender and technology over the decades, examine the correlation between gender and EO and GIT, and discuss how SERVIR-HKH integrates gender concerns in its programs and activities.

15.2 The Gender and Technology Question

Links between gender and technology in terms of symbols, identities, access, control, and use have always been critical issues of discussion in the gender and development sector. This relationship between gender and technology has been shifting over time, but in general, "technology itself cannot be fully understood without reference to gender" (Cockburn and Ormrod 1993:32). Industrial capitalism associated technology with hegemonic masculinity, whereby technologies were for men—to be produced, wielded, and controlled by them (Caputi 1988; Faulkner 2001). Vast advances have been made in technology, particularly EO and GIT, and similarly, much transformation is taking place in women's spaces in terms of their rights, education, roles, and relations at the household and community levels. As a result, the relationship between gender and the array of EO and GIT applications and tools have also undergone changes. Deliberations on the importance of these technologies and applications and on their social, political, and ethical implications began in the 1980s with the view that EO and GIT technologies can have both positive and negative impacts on the people, and that the nature of the impact varies depending on the social groups (Bourgue and Warren 1987; Harding 1986). However, more critical debates and discourses on these technologies and applications and their links to society emerged in the 1990s (Chrisman 1987; Craig et al. 2002).

During that time, the main thread of the gender and technology discourse, in terms of EO and GIT, revolved around pro-technology and anti-technology perspectives (Fig. 15.1). The pro-technology perspective viewed these technologies and applications as tools for liberating women from the drudgery-ridden daily tasks,

Fig. 15.1 Discourse on gender and GIT during a training event. Photo by Rajendra Shakya

while the anti-technology view regarded these technologies and applications as tools that perpetuate and reproduce gender inequality (Faulkner 2001). This more or less simple discourse then shifted to whether EO and GIT is masculinist or neutral in nature. These technologies and applications have often been termed as masculinist for the reason that they were mostly used for generating scientific knowledge for national defense, land management, and environmental assessment—sectors that were/are typically male dominated, which also rely only on secondary data, often not including social dimensions into the whole equation (Roberts and Schein 1995; Sheppard et al. 1999). The other view considers these technologies as gender neutral and not masculine and therefore can be positive for women in many aspects (Henwood 1993; Plant 1997; Oldenziel 1999). It is then argued that these technologies and applications rely on data exploration and layering and visualizations which can be used to construct and generate social and gender dimensions (Kwan 2002a; McLafferty 2005; Schuurman 2002).

Over time, the gender and technology discourse has moved away from these binary views, and the recent literature presents a more nuanced view that focuses on the social construction of technologies and their impacts on gendered social relations (Bray 2007; Faulkner 2001; McLafferty 2005; Wajcman 2000). Stemming from the view that both gender and technology are socially constructed and socially pervasive, this perspective would have it that there are "tight connections between them with technology shaping gender and gender shaping technology" (Lerman et al. 2003:5); and that the two are mutually constituted and "one cannot understand technology without reference to gender" and similarly, "one cannot understand gender without reference to technology" (Faulkner 2001:90).

With this perspective, began the emergence of feminist scholarship within the field of technological studies and the use of the term “feminization” by McLafferty (2005:39) in the context of GIS; she argued that by bringing in changes in the use, construction, and application of GIS, technology can be rendered “more compatible with feminist understandings of research and practice”. Several important GIS researchers also emphasize that community participation leads to a public participation GIS (PPGIS) platform which brings together diverse disciplines, including those of political economy, community development anthropology, political ecology, and the social sciences (Craig et al. 2002). These innovative efforts and initiatives have led to the incorporation of qualitative multimedia information into EO and GIT to complement each other and have allowed researchers to portray and reveal the multilayered and multifaceted dimensions of communities and places and give voice to the research subjects (Matthews et al. 2001). The influence of feminist geographers and social scientists has moved EO and GIT technologies far “beyond the detached, command-driven systems that predominated two decades ago”, but this influence “is unevenly spread across” EO and GIT research and applications (McLafferty 2005:40).

15.3 Gender and EO&GIT: Without and Within

EO and GIT technologies and applications are accessible to a wide range of users and touch people’s lives closely. Hence, this calls for a closer look and analyses of the technologies as well as beyond their technological uses. Focusing only on the technology means to ignore those social, political, and economic structures of power that affect and shape these technologies and applications (Bosak and Schroeder 2005; Pavlovskaya 2018). Considering these technologies outside the “context of power” may not only reinforce the unequal power relations but also limit the role of these in “conservative social projects and stifle [the] progressive constructions” of these technologies (Pavlovskaya 2018:5). It is vital to (a) understand how technologies impact the lives of women and men, and how they influence and shape gendered social relations; and (b) examine how gender norms affect the development and content of, as well as access to, these technologies.

Therefore, we examine the gender and EO and GIT correlation from two aspects: broader gender concerns of access to and impacts of these technologies—we term this aspect “Without”; the inclusion or exclusion of gender concerns in the EO and GIT sector and content—we term this “Within”.

15.3.1 Without

“Without” is used for the broader concerns that lie outside of the actual content and discipline of EO and GIT. Thus, this depicts the correlation between gender and EO and GIT in terms of the differential access to these technologies based on gender and social norms and practices and the differential impacts on the diverse gender and socioeconomic groups.

Access: Access to and control over resources is gendered (Gammage et al. 2016), and EO and GIT are very powerful and important resources as these applications offer a wide range of opportunities for instance, agriculture- and health-related information services. Gender norms and practices play an important role on who accesses these technologies. Due to this, access to and adoption of these technologies have not been uniform and vary based on gender, age, socioeconomic status, class, and geographic location. The gender structure and norms assign women a subordinate position vis-à-vis men, and they face numerous barriers in terms of finances, knowledge, skills, and mobility due to patriarchal relations in the household and community. For example, the gender division of labor plays a major role in the use of EO and GIT. Women, due to their conventional gender role of taking care of the household and family, which takes much of their time, are less likely to use these technologies and tools, whether it is for adding information (such as in maps) or for getting information (Liff et al. 2004; Stephens 2013). Another example is of people from lower socioeconomic groups having less access due to their financial status, while those living in remote locations also have a problem of access because of the non-availability of these technologies in their areas. Thus, access to such technologies is shaped by gender and social norms, economic (financial) resources, and geographical location (Kwan 2002b, c; McLafferty 2005). This has resulted in a nuanced digital divide between women and men, between socioeconomic classes, and between geographic locations, leaving those without access to these technologies more disadvantaged (United Nations 2020:2).

Impacts: EO and GIT have become more widespread with its uses ranging from complex and formal ones—such as for policy development and planning; management of resources, disasters, and risks; and warfare and surveillance—to the more common everyday uses such as for information, education, and shopping. This has extended the impacts of these technologies into many realms of everyday life. However, the impacts vary by gender as well as by age, class, and socioeconomic status since sociocultural norms and practices have a strong bearing on what kind of EO and GIT diverse people seek, how and for what they use them, and how they respond to these (Faulkner 2001; Chen et al. 2002). These technologies are influencing women and men's activities and behaviors and also changing their social and spatial interactions and boundaries.

EO and GIT are also being widely used for surveillance and monitoring by institutions, corporations as well as by individuals, which shows a clear link to power. Those in power are the ones who use the technologies for this purpose, and by doing so, it further augments their power (Haklay 2013; Leszczynski and Elwood 2015). This has enormous implications for both women and men, but there may be gender differences in the nature of the impacts. Women's greater domestic roles and responsibilities may make them more vulnerable than men to tracking by business houses in relation to purchases. There are numerous examples of how women's choices in household purchases are tracked, and based on this tracking, business houses flood women's social media and mailing sites with messages advertising the products they are likely to buy. These act as strong influencers on their choices and how they spend their money. At a more alarming level, the tracking systems can be used to perpetuate discriminatory and exploitative gender norms on women. For instance, exploitative partners, spouses, and family members can easily use these technologies to monitor women's movements and ensure their compliance with family or cultural norms and punish those women who violate these norms, thus reinforcing traditional gender roles and relations (Dobson and Fisher 2003).

Opportunities: EO and GIT tools and applications have the potential to reshape gender roles and relations in favor of women. These technologies open up many opportunities for women to ease their workload by enabling them to pursue alternative ways of carrying out household tasks; they also provide them with options to work remotely (Goyal 2011). This could lead to changes in the gender division of labor, and as with more time on their hands, women will get more opportunities to take up professional, paid work (Kotkin 2001). These technologies are also a valuable resource for social capital as they provide a huge scope for social networks (Boneva and Kraut 2002). They allow people to maintain and expand their contacts, which are particularly useful for women, giving them a sense of connectivity and support that can be empowering, given their lower mobility. This can be particularly significant for women in cases of domestic violence as the technologies can give them quick access to help and support. Another great example of EO and GIT as an opportunity for women is when these applications are used for gender-sensitive urban and town planning that respond to their needs and reduce spaces of violence. For instance, a simple streetlight can thwart violence. So, such technologies secure for women spaces they can safely operate in (Fenster 2005; Fesenko and Bibik 2017; Shirazi 2018; Carpio-Pinedo et al. 2019).

15.3.2 Within

The term "Within" is used for the aspects that fall inside or within the content, discipline, and sector of EO and GIT. Feminist geographers have indicated that power relations shape the construction and use of technologies such as EO and GIT, and that the development of these technologies in a particular context is influenced by the prevailing power relations (Sheppard et al. 1999). Thus, "Within" examines the questions of inclusion or exclusion of gender concerns in EO and GIT content, discipline, and sector.

The EO and GIT discipline is dominated by men, both in the academia and in the workforce (Haggar 2000; Schuurman 2002). The underlying reason for this is the gender structure whereby gender norms and practices that favor men have historically given men the edge with regard to education and technology. Despite efforts toward supporting more women to enter this discipline and profession, they are still lagging behind, particularly at the professional level in this field (Holmes et al. 2015; Bernard and Cooperdock 2018; UNESCO Institute of Science 2018; and Popp et al. 2019). Studies also show that women do not have great interest or confidence to work in this field (Rome's et al. 2007; Yau and Cheng 2012).

This compels the need to critically analyze how and in what ways such technologies and applications as well as the discipline and profession get gendered (Faulkner 2001). Many studies have shown how gender bias is widespread and ingrained in the discipline and profession itself. For instance: there still exists hiring biases against young women as they may leave the job or interrupt their careers to start a family, and this would impact scientific outputs (Williams and Ceci 2015); female geoscientists are more likely to experience negative gender bias at their workplaces and in scientific organizations than their male counterparts in the form of unequal opportunities in research funding/grants, less opportunity to get higher and prestigious scientific roles and positions (King et al. 2018; Vila-Concejo et al. 2018); the work environment usually is women-unfriendly since there is lack of flexibility in work timing and inadequate infrastructure to support working mothers; and there is also the issue of lack of same-gender role models, mentors, and women-oriented networks (Hill et al. 2010; Reuben et al. 2014; Holmes et al. 2015).

On the content side, the advances made in these technologies allow the public to contribute to the user-generated content of EO and GIT, especially with the new and welcome concepts of open access and citizen science. But yet, the shadow of male domination looms large. A study by Stephens (2013:994) shows that there is a gendered difference in the quantity of contributions and "this gendered differentiation manifests with women as users of the maps and men as expert reviewers of local knowledge, which has the potential to reproduce and reinforce the gender inequalities because men who document their local knowledge are documenting their own norms, traditions and biases".

On the positive side, EO and GIT open up new information, data, understandings, and innovations that are valuable process-questioning and problem-solving tools when applied as an integrated and thematic-based application (e.g., in the cases of forestry and drinking water); this can be used in a range of sectors and to address critical issues that are faced by communities and governments (Sharp 2005; McGinn and Duever 2018). These technologies can support integrated evaluations of the gender dimensions of any sector through a combination of tools and applications (Walker and Vajjhala 2011). There are now growing efforts to incorporate and overlay gender-related qualitative information on EO and GIT which are contributing to the increasing interface of gender with these technologies (SERVIR-Mekong 2015). These tools are now being extensively applied by organizations and governments in areas such as transport, health, urban and environmental planning, and disaster risk management. Along with these, it is critical to integrate gender to address the issues of the most vulnerable and marginalized groups in society (Kwan 2002c; Walker and Vajjhala 2011; Shirazi 2018; Carpio-Pinedo et al. 2019).

It is self-evident that EO and GIT can promote and enable social transformation in important ways, such as by empowering women and marginalized groups, transforming gendered spaces, and by creating opportunities for a wider section of people to contribute to scientific content, advocacy, and to the establishment and running of community organizations and networks (Elwood 2008; Coulton et al. 2011; Pavlovskaya 2018).

15.4 Engendering the SERVIR-HKH Program

Gender is taken as a critical aspect in SERVIR Global, of which SERVIR-HKH is a part of, and in ICIMOD, wherein SERVIR-HKH is housed. SERVIR Global advocates and promotes interface of its services with inclusion of gender and social issues. It has also formed a SERVIR Network Gender Strategy with the overall goal to capture and disseminate lessons on improving gender equality, specifically with respect to making GIS/RS technologies and professions more gender responsive and equal. On similar lines, ICIMOD, with its overarching vision of "improved well-being of men, women and children of the HKH" and a strategic goal of advancing gender equality and inclusive development, gives high priority to gender in all its programs, and gender is taken as a crosscutting thematic area. Thus, SERVIR-HKH is mandated to integrate gender in the program, including in its approach, activities, services, and products. Integrating the aspect of gender is also critical for SERVIR-HKH to achieve its goal of improving upon the sustainable use of EO and GIT for environmental management and enhancing the resilience of the vulnerable population to climate change in the HKH region.

Looking back at the past decades, there are two major projects where ICIMOD worked on integrated gender and social aspects in GIS. The first project took place in 1996–1997 as an assessment of the comparative development status of Nepal's districts; this was conducted in collaboration with the Netherlands Development Assistance (SNV-Nepal). The primary aim was to provide a means of selecting priority districts for development assistance. The study used GIS to map the indicators of development at the district level. Indicators were developed for each of the following four dimensions: poverty and deprivation; socioeconomic, institutional, and infrastructural development; women's empowerment; and natural resource endowment and management. These were combined with physical topography, i.e., slope steepness, to construct a development index for each district (ICIMOD 1997). The second project took place in 2003 when ICIMOD partnered with the Central Bureau of Statistics, Nepal, and SNV-Nepal to update the report using more recent data. The updated study used as much as possible the same indicators as in the previous study and also followed the same methodology so that the two studies would be comparable (ICIMOD 2003).

A more systematic and focused approach on integrating gender took shape more recently when SERVIR-HKH developed a gender strategy and a detailed gender action plan. The gender strategy was developed to ensure systematic and focused gender integration and guide the program. The gender strategy identified three areas of concern where there was a need to integrate gender: in content; in access; and in professional-level participation.

Content: Incorporating gender-related information into the content in terms of geospatial products, services, and applications was crucial so that these could be used as tools for raising awareness on gender-related issues, influencing policies, and enabling communities to minimize gender-unequal risks and thereby help address gender inequality for more sustainable development (SERVIR-Mekong 2015).

Access: The information and products generated by SERVIR-HKH should be accessible to all the different gender and social groups in society, irrespective of their educational, gender, and other socioeconomic status. Furthermore, the technical information available in the form of maps and other applications should be translated, tailored, and narrated in a language that is readable and understandable for people with limited knowledge on maps and applications. These are also critical to achieve the ultimate goal of SERVIR-HKH: connecting space to village. Moreover, this part of the strategy gives due weightage to effective dissemination channels and mechanisms that can reach out to women and different socioeconomic groups.

Professional participation: As discussed in Sect. 15.3.2, there is a visible gender gap at professional levels in the geospatial professions. Globally, the number of women professionals in the geospatial sector is minimal and same is the case with HKH. A study says that among the researchers in the world in this field, only 19% are women (UNESCO Institute of Science 2018). This study reports that although women's enrolment in bachelor's degree in the fields of science, technology, engineering, and mathematics is equal or even slightly higher than men, their number in higher studies is rather low. This indicates that while women have the enthusiasm to pursue a career in geospatial studies, they cannot sustain it at the higher level and build a career in research. Numerous studies, which are cited in Sect. 15.3.2, show that women face different hurdles compared to men at work. Thus, there is an urgent need for the HKH region to address the issue of women's representation at the professional level.

SERVIR-HKH has adopted a "services" approach for ensuring the effectiveness of its services to help developing countries resolve the challenges in the priority service areas. The approach, therefore, is to integrate gender in all the services and make these services gender (as also socially) sensitive and responsive. The strategy is to frame the services so as to address gender needs and concerns in content, interpretation, and analysis. This entails systematically considering and addressing gender disparities, constraints, and opportunities to ensure that: the services under each of the thematic areas are gender sensitive and responsive; the dissemination processes of the services are designed in such a way that they are accessible to women and men of various socioeconomic groups; and the approaches that are adopted are affirmative as to bridge the gender gap at the professional level. In this regard, three strategies were adopted to integrate gender in order to achieve the three strategic objectives:

(i) Integrate gender in the Theory of Change (ToC) and in the monitoring, evaluation, and learning plan:

Integrating gender in TOC and in the monitoring, evaluation, and learning plan is crucial as this paves the way to practically and realistically mainstream gender at all stages and activities of a program. Hence, the strategy of the SERVIR-HKH ToC is to appropriately consider and integrate gender by setting up, from the very beginning, gender targets wherever necessary and relevant and establish gender-disaggregated monitoring data to support gender analysis; this also entails documentation and sharing of gender integration in ToC. (More details on ToC are in Chap. 18.)

(ii) Combine various gender methods, tools, and sensitivities during service design and implementation:

It is essential to integrate the geospatial information with appropriate gender-disaggregated data for developing gender-sensitive/-responsive services. Therefore, while developing the services, the interpretation and analysis will not only limit to EO, but rather the ultimate conclusion will be drawn based on integrating the geospatial data with social and gender analysis. For instance, SERVIR-HKH aims to generate community-level gender-disaggregated data to inform gender-responsive policymaking in Nepal. The Community Forest User Groups (CFUGs) in Nepal are in a position to gather local-level data and insights, and there is also in place a new national policy that encourages more women to participate in their management. In this regard, in partnership with *Hariyo Ban*, data from specific districts in Nepal are being collected to understand how women's access to CFUG decision-making will have an impact on forest conditions, the types of natural resources the community focuses on managing or collecting, and on how the CFUGs spend the money that is collected.

SERVIR-HKH believes that gathering such data paves the way for analysis and can be used by the government to design appropriate gender-responsive policies to encourage further engagement of women in decision-making spaces. This data can also be used by the government to determine funding allocation to the CFUGs. Though the data collection process has not yet begun, SERVIR-HKH anticipates serving an important role in the *Hariyo Ban* project in the following ways: it hopes to address the quantitative data gap in the project, develop data visualizations using GIS services, and convincingly present the data to the government. SERVIR-HKH, through *Hariyo Ban*, aims to have a lasting impact on policymaking in Nepal.

In the user-engagement process too, gender dimensions will be taken into consideration. For SERVIR-HKH, users are mainly partners who are involved at the service level in the development of the products and services either as co-creators, co-designers, co-implementers, and as ultimate or potential beneficiaries.

For this, SERVIR-HKH will engage and partner not only with the government agencies that are the immediate users of the services, but also with the end beneficiaries such as federations and associations of women and men farmers, water and forest users' associations, and community disaster management groups. This will benefit by way of ensuring that the services incorporate gendered perspectives in the analysis and interpretation of the information that is produced. (More details on how user engagement considers the gender perspective are given in Chaps. 17 and 18.)

The dissemination of the information that is available from the services will also consider gender dimensions in various ways, such as preparing these in a language that is suitable for the ultimate users and also disseminate through user organizations via printed material and audio-visual media. (Details in Chap. 17.) Moreover, the most effective dissemination channels and mechanisms will be identified to reach out to women and other socioeconomic groups.

(iii) Build women's leadership and create gender champions in SERVIR:

As has been discussed in Sect. 15.3.2, the EO and GIT field is male dominated, and as long as women remain in low numbers in this field, the working environment will continue to be biased against them, and patriarchal attitudes and processes will continue to reign. Therefore, it is imperative that more women enter this field. The strategy for this is to proactively seek and recruit women in the sector by applying affirmative actions and a positive discriminatory policy; include women in trainings, workshops, and related events by reserving 33–50% seats for them and bringing women as speakers and resource persons in seminars, conferences, and workshops; empower and support young women in this field through targeted capacity building programs; and build and foster gender champions within the SERVIR-HKH program.

In addition to the gender strategy, SERVIR-HKH has also developed a detailed gender action plan. In 2017, based on the recommendations of the gender audit of 2016, ICIMOD initiated the development of a gender plan of action for all its programs and initiatives as well as for the institution as a whole, with the aim of increasing gender responsiveness in its works and processes. The main goals of this are threefold: ensure gender integration at ICIMOD; operationalize the gender policy; and create an accountability mechanism. A detailed procedure was laid out to develop the gender action plan that began with the outcome statement of the regional program of ICIMOD associated with.

This procedure was followed rigorously by the programs, including SERVIR-HKH (Table 15.1). In this way, the gender strategy is used as a guide and approach to integrate the gender aspect in SERVIR-HKH, while the gender action plan outlines the objectives and actions, spells out the gender-specific indicators to monitor and track, lists the inputs and resources that are required, identifies the responsible person/team, and sets a timeline. The implementation of the gender action plan will come up for evaluation in 2021. This will investigate, through meetings/workshops, as to whether the targets and actions have been accomplished

Table 15.1 Procedure for developing the gender action plan

Procedure for developing the Gender Action Plan

		Outcome statement		
		Dimensions	Gender issues	Objectives
Step 1	Identify the dimensions of the stated outcome Identify the gender issues in each of these Given the issues, set gender-specific goals/ objectives			

		Objectives	Challenges	Opportunities	Actions	Indicators
Step 2	What are the challenges in meeting the objectives? What are the opportunities? What are the actions needed? What are the indicators to monitor and show progress?					

		Objectives	Actions	Resources			Responsibility	Timeline
				Financial	Human	Other		
Step 3	What are the actions? What resources are required? Who will be responsible? What will be the timeline?							

and then submit a progress report to the Strategic Planning, Monitoring and Evaluation (SPME) Unit of ICIMOD.

15.5 Conclusion

With EO and GIT entering the public realm with more uses and users, there is no doubt that they made an immense impact on several spheres of people's lives. Exploring and examining the connections and correlations between EO and GIT and gender shed light on the interlinkages between the two. It is evident that even today, this sector is predominately male dominated, which is linked to the gender norms that are prevalent in society, due to which knowledge and products are often developed by men. However, it is also clear that this scenario is undergoing rapid changes. EO and GIT have gone through transformations over time with inputs from feminist geographers which have been (and are still being) enriched by incorporating novel ways of thinking, thereby signaling a shift from the priority accorded to the methods of dominant technology and quantitative data, to combining these with methods that allow incorporation of contextualized, qualitative information. And riding on such a merger, these technologies and applications can aid in informing, broadening, and visualizing additional, and sometimes new, information in gender and feminist studies and discourses.

For SERVIR-HKH, the connection between EO and GIT and gender and social issues lies in the fact that these applications and technologies, when combined with the methods that address the needs, interests, and priorities of women and other marginalized groups, can contribute to equitable socioeconomic development, poverty reduction, and increased resilience. An example of this has been given a section in this chapter on generating community-level gender-disaggregated data to inform gender-responsive policymaking in Nepal. SERVIR-HKH has effectively laid down the gender-integrated approach in its programs and activities. The challenge has been in getting the technical professionals to internalize these complex and nuanced understandings. This is compounded by the involvement of very few gender and social scientists (in terms of numbers and time) in the SERVIR-HKH project; this makes it difficult to ensure that the plans, steps, and activities laid down in the gender strategy are followed thoroughly.

One of the ways forward is to strengthen gender integration in the EO and GIT sector as well as SERVIR-HKH; this would mean roping in more gender and social scientists as part of a core group who are as closely involved as the technical professionals. Such a strategy would go a long way in making both sets of professionals understand each other's views, and then, they could move forward together in a meaningful way, whether by capacity building through various trainings and workshops or through other means that are tailored according to the needs of the activity, output, or outcome. In the HKH region where climatic and socioeconomic changes are having an adverse impact on natural resources and livelihoods, the need to integrate gender in EO and GIT is critical and urgent as this will bear two important results: It will enable researchers and practitioners to set better target interventions for women and men on the ground in a wider geographical space; and second, it can fashion the applications or services in an effective and powerful manner whereby there is heightened awareness about gender issues. All this will also contribute to empowerment and address gender inequality by enabling communities to minimize gender-based unequal risks in various contexts and situations (for instance, in the areas of disaster risk reduction and building adaptation and resilience). Thus, on a broader note, EO and GIT can serve as a catalyst for transformative change—by addressing the issues of gender and social inequality as well as the unfair power distribution systems that are at play, these technologies have the wherewithal to create a just and level-playing field.

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Chapter 16
Communicating Science for Informed Decision-Making

Birendra Bajracharya, Utsav Maden, Devrin Weiss, and Leah Kucera

16.1 Introduction

SERVIR's primary objective is to use Earth observation (EO) information and geospatial information technologies (GIT) to address challenges in areas of societal concern such as food security, land use and land cover, water resources, weather, and natural disasters. With a tagline of "connecting space to village", SERVIR-HKH aims to build the capacities of people and institutions in the HKH region to integrate science and technology into the decision-making processes. To achieve these broad and ambitious objectives, SERVIR-HKH provides scientific information to a wide range of audiences with different societal contexts (Chap. 1). A picture is worth a thousand words, they say; EO satellites provide pictures of the Earth surface which help scientists to understand the dynamics of natural and anthropogenic processes. Similarly, GIT tools enable analysis and visualization of data, not only for scientific exploration but also to help communicate the information to the intended users in the form of maps and charts. The cartographic principles applied during the map-making process ensure that the scientific information undergoes minimum distortion while communicating to the target audiences.

People, typically, consider their own needs, knowledge and skills, values and beliefs as well as scientific information while making decisions. Therefore, they will make choices consistent with scientific evidence only if the science is

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_16

communicated effectively (NASEM 2017). Different or contradictory messages conveyed by multiple sources often generate uncertainty in the science or its implications, and usually do not aid informed decisions (Burns et al. 2003). Therefore, SERVIR must ensure that the information and knowledge are shared and delivered to people through relevant channels in appropriate formats, and at appropriate timings, to enable them to make informed decisions. This requires an effective communication system aimed at helping people understand the science relevant to a decision while also recognizing that other factors will affect their actions (NASEM 2017).

The recent technological advancements have also brought about enormous opportunities in scientific communication. The advent of mobile devices and smartphones and wider penetration of the internet ensures that a wider audience has access to the scientific information that is being disseminated through a wide variety of media such as web portals, blogs, videos, and social media. Current technological advancements have also made it possible to develop customized information services for the targeted users; they have also enabled and facilitated user feedback and aided in gauging the social impact of the information services.

In the context of SERVIR, the communication means help in raising awareness about its applications and services; they enable the sharing of information generated by these applications with the targeted users, thereby aiding the decision-making process; they also open up many platforms to generate and receive feedback. As the users are central to SERVIR's service planning approach (Chap. 2), communication is an integral part of user engagement for the development of constructive, collaborative, and enduring stakeholder relationships (UNGGIM 2020). Communication plays a fundamental role in fostering social awareness and in facilitating public democratic dialogue, thereby building a shared understanding and contributing to evidence-based policy (Hovland 2005). Here, we present the approaches and practices adopted by SERVIR-HKH for effective communication and sharing of its products and services, and our learnings from the HKH region.

16.2 Knowledge Management and Communication Strategy

A strategic communication framework is important for successful exposure and branding, user engagement and for the effective delivery of data, information, and knowledge products and services. As SERVIR-HKH primarily deals with geospatial information and modeled data, it needs to follow appropriate mapping conventions for effective visualization of data and analyses. Therefore, the proper identification of the target audiences and their access to various media platforms are fundamental considerations while designing an effective knowledge management and communication strategy. While ICIMOD has its knowledge management and communication strategy and institutional branding policies in place, SERVIR-HKH also needs to account for the co-branding requirements (USAID 2016) as part of a global network led by USAID and NASA. In this context, while the visual branding requirements of the host and donor organizations set precedence, SERVIR-HKH also needs to ensure scientific accuracy and relevance in the knowledge it generates and the messaging it carries out. The marketing collateral that is produced also needs to portray the positive connection between satellites and people and connect with a regional audience.

Taking these requirements into account, SERVIR-HKH developed a Knowledge Management and Communication (KMC) Strategy to guide targeted communications, sharing, and dissemination of its information and knowledge for greater impact, better and broader outreach, and efficient internal communications. The strategy aims to support the uptake of its services, products, and applications by the target audiences in order to bring about behavioral change, thereby influencing positive policy and development outcomes. The different target audiences, their

Table 16.1 Communication strategy for different audience type adapted from ICIMOD (2013 and 2018).

SERVIR audience type	Why is it important?	Communication channels	Activities	Goals
Implementing partners National government ministries/departments or subnational offices, universities/research centres	Directly associated with research or training, sharing of data and information	Knowledge products – reports, handbooks, information sheets Events – national/regional meetings, workshops, knowledge forums, joint organization of/ participation in international conferences, targeted events	Generation of knowledge products/training materials Joint workshops, training, outreach events Reports, peer-reviewed articles, books	Build capacities so that partners are more capable and better able to use Earth observation and geospatial information Common goals of raising awareness, complementing each other
	Adoption of services, lobbying for policies	Digital engagement–website, science applications Personal/official communications	Advocacy, policy dialogues	Adopt right technologies and methods to support informed decision-making, promote SERVIR-HKH and its work
Intermediaries National government ministries/departments or subnational offices, extension agents, NGOs, media, relevant donor-funded projects, associations/cooperatives (e.g. of business, industry, farming), private sector	Contribute to research, data and information sharing	Information exchange, participation in events Personal/official communications	Workshops, trainings, outreach events	Gain information on needs and priorities in related service areas
	Raising awareness, information exchange, promoting and supporting SERVIR's work and Earth observation/GIT agenda	Website, interviews/surveys, press events and releases to provide information	Surveys, consultations, dissemination workshops	Promote SERVIR and its work, and the societal benefits of Earth observation/geospatial information technology
Other partners Development agencies, donors (including USAID)	Financial contributions, project support	Personal/official communications, knowledge products	Timely reports, updates	Inform, assure, and comply with donor demands
	Cooperation, joint projects, information sharing	Annual report, international and regional conferences, meetings, website	Reports, events, project activities and updates	Effectively plan and implement joint projects, find potential donors/ partners
Beneficiaries Farmers, communities, private-sector service providers, universities/ research centres	Inform, advise, support Raise awareness Selection of important partners for private–public cooperation	Trainings, media, knowledge products, newsletters, website, case studies, success stories	Awareness campaigns, meetings, seminars, study tours, visits	Build capacities, promote SERVIR and its work, and the societal benefits of Earth observation/geospatial information technology Establish greater private–public cooperation and joint projects

importance, the adopted communications channels, activities, and the end goals identified in the strategy are presented in Table 16.1.

16.3 When Communication has a Key Role to Play?

Communication plays an important role in all aspects of SERVIR-HKH's program design and implementation. More specifically, communication plays a critical role in the areas identified below

- User engagement during needs assessment and user consultations
- Dissemination of scientific data and information through the SERVIR-HKH services
- Capacity-building activities
- Promoting SERVIR-HKH on the web, social media, and other platforms
- Documenting use—use cases to capture how a service is used
- Regional knowledge forums and global outreach.

The design and development of knowledge products and marketing collateral need specific considerations for each of the aforementioned areas.

16.4 User Engagement During Needs Assessment and User Consultations

As part of the service planning process (Chap. 2), SERVIR-HKH identifies its users and engages with them further to assess their needs. It organizes consultation workshops at the national and regional levels with the key stakeholders working in the SERVIR-HKH's service areas to carry out a thorough needs assessment of user requirements (Chap. 3). Effective two-way communication plays a crucial role here to help understand the users' needs and priorities, and also to express the capability to address the needs through the existing EO data, GIT infrastructure, and scientific methods, as well as through other available resources.

Such workshops are designed with two-way communication in mind—both listening to and learning from the invited stakeholders and sharing information on SERVIR's capabilities and available resources. These consultations begin with a session focusing on information exchange where the participating institutions highlight their mandates, priorities, and relevant work activities through short presentations at the plenary. This learning and sharing process ensures that all the participants are well informed and helps explore areas of commonality or overlap. The sessions that follow focus on collective thinking on problems and opportunities. As for the facilitated group activities, they discuss challenges, identify opportunities and connections, set priorities, and leverage the collective expertise and points of view of the attending quorum to set a course for relevant, demand-driven activities.

The needs assessments process at user consultations help identify the key partners in the co-development of services. The follow-up meetings with the identified partners help to develop work plans, find agreement on the methodologies and data-sharing arrangements, and enable the calibration and validation of components as part of the co-development process. The organization of regular face-to-face and virtual meetings with the identified national partners also helps in reviewing progress and communicating updates.

During the service development cycle, national outreach and dissemination workshops are conducted in collaboration with the national partners to help communicate the programmatic developments and to solicit feedback from the relevant stakeholders. These national outreach workshops are carried out in SERVIR-HKH's focus countries—Afghanistan, Bangladesh, Myanmar, Nepal, and Pakistan—and are often delivered in the vernacular language and led by the national partner wherein SERVIR-HKH provides technical oversight.

For example, organizing dissemination workshops for flood-prone areas in Bangladesh in partnership with the Bangladesh Water Development Board (BWDB)/Flood Forecasting and Warning Centre (FFWC) was instrumental in reaching out to the relevant stakeholders and in informing them about assistance from SERVIR-HKH in developing appropriate flood warnings. Similarly, Afghanistan's first comprehensive glacier database was launched at a dissemination workshop organized at the Ministry of Energy and Water's campus in Kabul. These events served to showcase services and launch joint knowledge products while soliciting and strengthening further partnerships and collaborations.

16.5 Dissemination of Scientific Data and Information

SERVIR-HKH's core objective is to generate scientific information to support informed decision-making. Under the four priority service areas identified for SERVIR-HKH (Chap. 1), several services have been developed which produce information products in the form of maps, charts, and expert interpretations. These services include web-based applications, also referred to as science applications, and are designed to help the users address specific problems under the designated service area.

All the science applications developed under SERVIR-HKH follow a particular schema that defines the placement of different components and controls so as to enable the users to know intuitively where a component is placed. All these applications implement a responsive design, use the approved color palette, and include an acknowledgement/additional information section to provide more information about a particular application. Each science application has a specific URL, follows a common nomenclature for easy reference, and is linked to the science applications page on the SERVIR-HKH website.

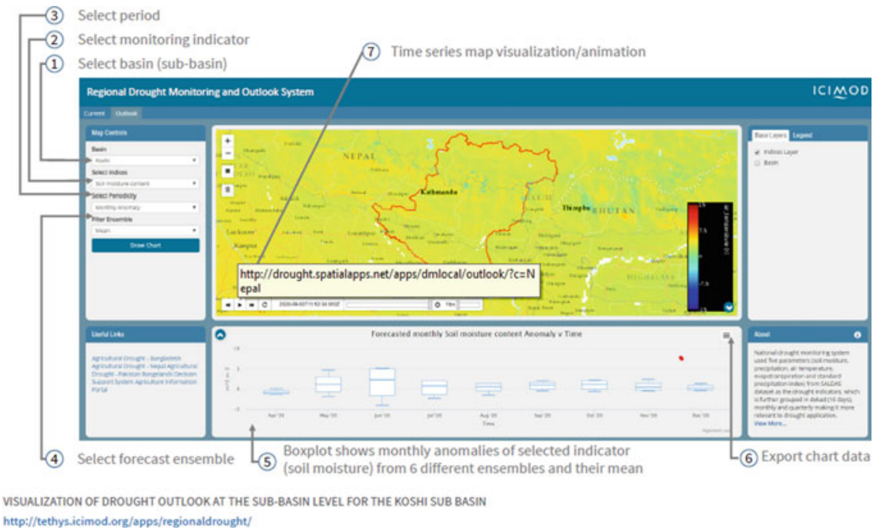

Fig. 16.1 An example of science application for scientific data visualization and dissemination

For example, the Regional Drought Monitoring and Outlook System (RDMOS) for South Asia (Chap. 4) is an operational service that produces reliable drought indicators for the HKH region and also provides seasonal outlooks at four-month intervals to support drought management and its preparatory processes (Fig. 16.1). The system generates data in the form of raster grids that show anomalies against long-term average values. A web-based graphical user interface helps translate this data as scalable color-coded maps and interactive charts, which provide a user-friendly means to analyze drought indices across river basins, national administrative boundaries, or a predefined area of interest, and to aggregate results in terms of cropping seasons. The system aids the agriculture extension workers and professionals involved in agro-advisory services who can use the information and couple it with their expert knowledge.

16.6 Capacity Building

Training and capacity-building activities are integral parts of SERVIR-HKH (Chap. 14). Announcements around capacity-building events and the opportunities specific to SERVIR-HKH are made available on the website and shared through ICIMOD's monthly news digest, social media feeds, and mass emails, as applicable, in order to facilitate competitive placement opportunities for women and disadvantaged groups (Fig. 16.2).

The capacity building activities entail preparation of training manuals with maps, illustrations, and guided walk-throughs to handhold the trainees through theoretical

Fig. 16.2 Illustration for use in email campaigns and social media during the open call for application

concepts and hands-on exercises (Fig. 16.3). There are also customized training manuals for training on applications of EO and GIT in the different service areas; these consider the level of the targeted trainees, ranging from beginners to advanced users. As for event-specific materials—background notes, agenda, training materials, tutorials, and resource books—they undergo edits for consistency of language and to ensure the use of gender-aware language. Then there are the marketing collaterals developed for flagship training events which take into consideration regional sensitivities in the imagery and the illustrations that are used.

Post-event communication materials in the form of news, video clips, testimonials from participants who have benefitted from a particular training, and success stories highlighting how certain users have gained from the adoption of a product or service are important in telling the SERVIR-HKH story.

As an example of the broad range of events organized by SERVIR-HKH, a list of consultations and training workshops on the flood early warning system for Bangladesh is presented in Table 16.2.

16.7 Promoting SERVIR-HKH on the Web, Social Media, and other platforms

Promoting SERVIR-HKH for visibility at local, national, regional, and global levels is a major objective of the SERVIR-HKH KMC strategy. This entails a coordinated effort in creating and retaining a brand image, and in the timely communication of SERVIR-HKH's achievements and impacts. The major activities involve:

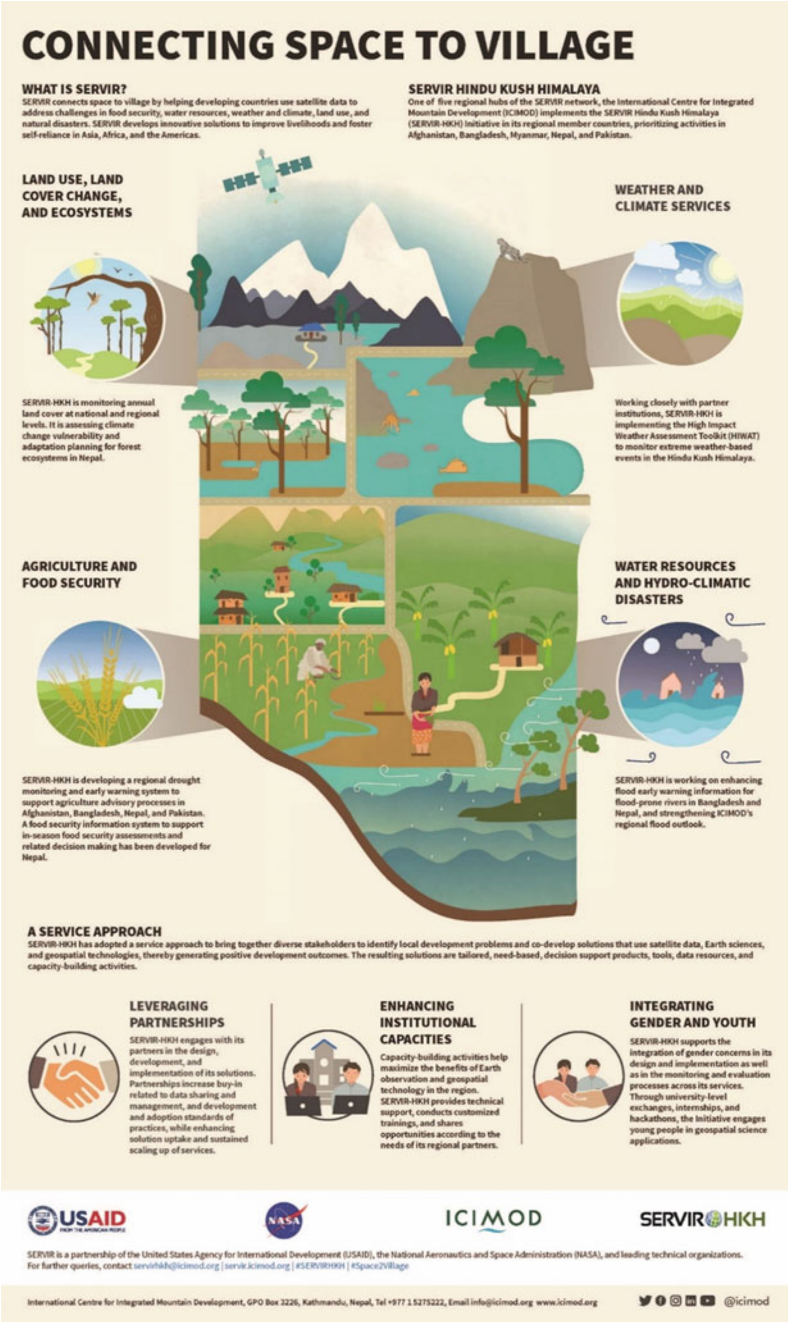

Fig. 16.3 The "connecting space to village" poster designed as a giveaway for a schoolteacher training programme (https://lib.icimod.org/record/34552)

Table 16.2 List of SERVIR-HKH events focused on the thematic area on water resources and hydro-climatic disasters in Bangladesh

Dates	Title
26 January 2016	National consultation workshop on "Needs Assessment for SERVIR-HKH" in Bangladesh
11–15 July 2016	Regional workshop on Impact Pathway, Partnership & Communication Strategy
19–22 September 2016	Training on SRTM-2 digital elevation model (DEM) applications
20–21 April 2017	SERVIR HKH Applied Science Team stakeholder workshop
25–26 April 2018	Training on Transboundary Streamflow Forecasting Tools
25 February 2019	Stakeholder consultation workshop on "Preparation for 2019 flood: expectations & suggestions", in Sirojgunj
26 February 2019	Stakeholder consultation workshop on ˋPreparation for 2019 flood: expectations & suggestions", in Bogura
5 March 2019	Stakeholder consultation workshop on "Preparation for 2019 flood: expectations & suggestions", Motijheel, Dhaka
6–7 March 2019	Introductory training on Hydrostats
13–14 May 2019	Training workshop on Applied Science Team (AST) forecasting tools
5–9 July 2019	Training workshop on Google Earth Engine, Bangladesh
22–23 October 2019	Regional Knowledge Forum on Early Warning for Floods and High-Impact Weather Events
24 October 2019	Stakeholder consultation on "SERVIR-HKH flood and extreme weather early warning systems: achievements and way forward"

- Branding strategy and marking plan
- Knowledge products and marketing collaterals
- Digital platforms
- Engagement with the media
- Social media presence.

16.7.1 Branding Strategy and Marking Plan

A brand identity helps communicate the strategic point of view of an institution or an initiative, thereby creating values and cultures that circulate in society as conventional stories (Holt 2003). A Branding Strategy and Marking Plan included in the KMC strategy ensured the consistent usage of the visual brand identity and brand narrative for SERVIR-HKH across all knowledge products and marketing collaterals. The visual identity, brand elements, and key messages from the SERVIR Global Program were adapted for a regional focus, building on ICIMOD's regional presence while capitalizing on the internationally adopted brand identities of NASA and USAID.

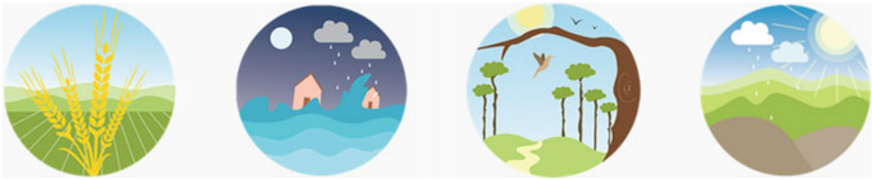

Fig. 16.4 Brand elements around the four thematic priorities developed for usage as marketing collateral

The three institutional logos—USAID's, NASA's, and ICIMOD's—and the SERVIR-HKH logo formed the primary visual identity of SERVIR-HKH, supported by iconography representing the four key service areas: agriculture and food security; land cover and land-use change and ecosystems; water resources and hydro-climatic disasters; and weather and climate services (Fig. 16.4). The SERVIR logo depicts a human figure at the centre of the Earth and represents a user-centric approach. These brand elements were reproduced across all knowledge products, ranging from the website to printed materials—information sheets, posters, and branded marketing collaterals—for a consistent look and feel across all products. The brand elements communicate the essence of the science applications being presented, while also making them visually appealing.

16.7.2 Knowledge Products and Marketing Collaterals

SERVIR-HKH commissioned and updated brochures, factsheets, information sheets, posters, and infographics in local languages (as needed) for dissemination to the target audiences (Table 16.1). Editorial photographs from the region and bespoke illustrations help convey the connection between space to village, and the severity of natural disaster situations like droughts and extreme weather events. The use of such materials helped provide the context for the marketing collaterals developed for different outreach events—such as consultation workshops, country-specific fairs, and exhibitions and conferences. The marketing collaterals developed for country-specific fairs and exhibitions (Fig. 16.5) made SERVIR science more accessible and comprehensible to visitors.

While participating in the regional and country-specific fairs and exhibitions, and during the celebration of international days—GIS Day, Earth Day—that highlighted the contributions of EO and GIT to societal welfare, such collaterals provided good outreach opportunities for SERVIR while also helping it spread awareness on and spike interest in EO and GIT.

SERVIR-HKH also developed training manuals and video walk-throughs for relevant science applications, and short multimedia primers around the thematic topics and/or products and services. The training materials—presentations, exercises, and workbooks developed for different training—are available for free

Fig. 16.5 SERVIR-HKH/ICIMOD's poster display at the Geospatial World Forum 2018 held in Hyderabad, India (15–19 January 2018). Photo by Utsav Maden

download from its website. These manuals and walk-throughs were especially helpful during the hands-on exercises and guided the demonstrations for trainees, participants, and visitors, and have a life span beyond the training event as well.

16.7.3 Digital Platforms

A dedicated SERVIR-HKH website—servir.icimod.org—has been set up under a separate subdomain within ICIMOD's main domain. The website provides a one-stop gateway for access to information and data products specific to SERVIR-HKH. It serves as a landing page for the announcements, events, news, and success stories stemming from work under SERVIR-HKH across the four thematic areas and for activities specific to Afghanistan. Besides, various science applications, story maps, data sets, and knowledge products—information sheets, training reports, and manuals—specific to SERVIR-HKH have been collated from different in-house services and made available through the website. The site serves as a clearinghouse mechanism for services and knowledge products specific to SERVIR-HKH. The site has also been integrated with ICIMOD's institutional systems to provide the following:

– **Regional Database System (RDS) portal** <rds.icimod.org>: The data sets page on the website provides a dynamic list of data sets specific to SERVIR-HKH hosted on the RDS portal, ICIMOD's institutional repository, and clearinghouse for data.
– **Mountain Geoportal** <geoportal.icimod.org>: The science applications page provides a dynamic list of SERVIR-HKH-specific science applications hosted on ICIMOD's designated space for EO and geospatial applications.
– **Himaldoc** <lib.icimod.org>: The publications page provides a dynamic list of the knowledge products produced under SERVIR-HKH hosted on Himaldoc, ICIMOD's central document repository, and online digital library.

Further, an active events calendar provides information on upcoming and past events under SERVIR-HKH, while success stories and post-event communication keeps the users engaged. Updates on SERVIR-HKH's website are communicated across the wider SERVIR network during the monthly hub meetings.

The website also hosts a separate section on story maps. Story maps harness the power of maps and geography to tell stories, give the narrative a stronger sense of place, illustrate spatial relationships, and add visual appeal and credibility.

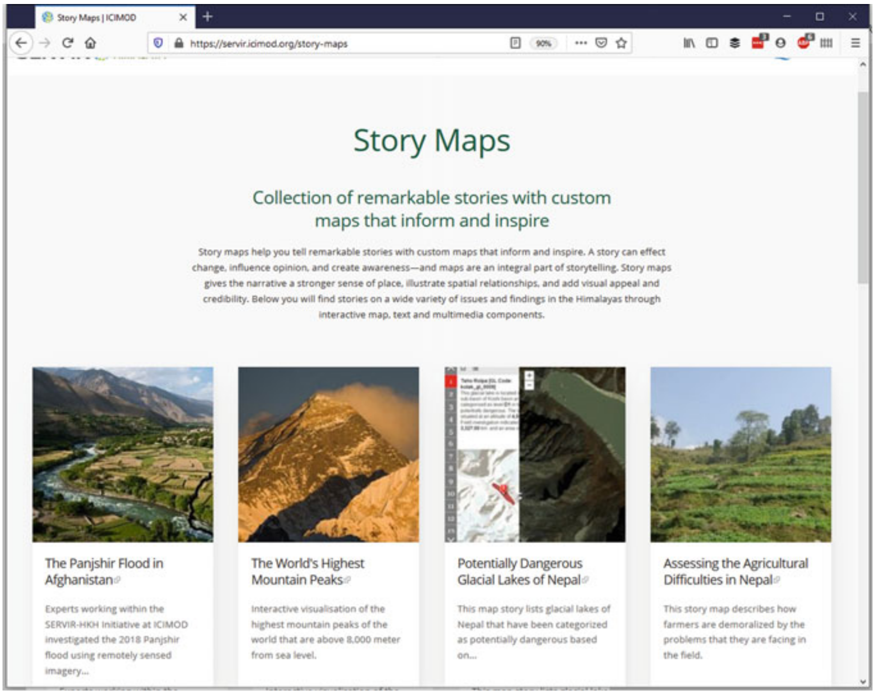

Fig. 16.6 SERVIR-HKH has published several story maps on a wide variety of issues and findings in the HKH by combining authoritative maps with narrative text, images, and multimedia content (https://servir.icimod.org/story-maps)

SERVIR-HKH has published several story maps on a wide variety of issues and findings in the HKH by combining authoritative maps with narrative text, images, and multimedia content (Fig. 16.6). These story maps serve as an important tool for public engagement and have been made available on the SERVIR-HKH website. These maps are also periodically shared via the institutional social media handles.

The underpinning of SERVIR-HKH's digital presence requires dedicated and skilled human resources conversant in knowledge management and communication, web development and standards, and also in geospatial information and standards. Besides, an editorial calendar, regular internal communication, and standardized operating procedures in-house and across the network, as well as monitoring and regular follow-ups ensure uptime and synchronize updates between the different systems.

16.7.4 Engagement with the Media

Often, the media does not fully appreciate the inherent importance of science due to inadequate scientific education and tends to misrepresent or obstruct rather than facilitate communication between scientists and the public. Close cooperation between scientists and journalists is important to fulfil the media's social responsibility to inform and educate the public (Fjæstad 2007). Engaged appropriately, the media can act as an intermediary and help translate our science into more accessible forms and relay it to a general audience. The media can help amplify our reach and help us with quality assurance by letting us know if our messaging needs to be simplified or fine-tuned. SERVIR-HKH releases press statements and media briefs around major regional and national outreach events and product launches. It also works closely with ICIMOD's media unit to identify relevant journalists to participate and contribute to outreach events. This engagement with the media has resulted in positive outcomes and reportage of SERVIR's work in major national and vernacular outlets in SERVIR-HKH's focus countries. Also, the links to media reports about SERVIR-HKH's work are routinely captured and made available as "media coverage" on its website.

Inviting journalists to national outreach and dissemination workshops as well as to regional knowledge forums were especially helpful in getting the message out on SERVIR-HKH's work in the region, while also educating the mediapersons on the ongoing work and capabilities of EO and GIT applications. In this regard, partnerships and engagement with the media through media-centric training workshops, editorial and knowledge partnerships, and story grants could help us in promoting and translating SERVIR-HKH's science, while also making it more accessible to a wider audience.

16.7.5 Social Media Presence

The evolution of social media platforms and their growing use by all sectors of the society provide unprecedented opportunities to reach large audiences, thereby enabling active engagement through online two-way communication (Third Wave 2013). Social media makes it possible to share and participate in a variety of activities and represent an increasingly important way for brands to communicate with the attractive audience segments (Ashley and Tuten 2015). These platforms are especially effective in real-time information dissemination, strategic communication, research, user relationship management, and brand promotion. SERVIR-HKH made use of ICIMOD's institutional social media handles on multiple platforms such as Facebook, Instagram, LinkedIn, and Twitter to engage with its audiences. #SERVIRHKH, #space2village #Data2Action were used as the hashtag to distinguish posts specific to SERVIR-HKH (Fig. 16.7). Its social media presence was actively supported by daily media monitoring and social listening to capture instances of SERVIR-HKH's work being featured in the media and social media. A dedicated social media calendar made optimal use of international days and major events to create campaigns for greater visibility and reach for SERVIR-HKH's services. SERVIR-HKH also supported the resharing of posts related to activities of other SERVIR hubs and the SERVIR Global Program.

Our social media campaigns have provided much-needed visibility to our work and directed traffic to the SERVIR-HKH website. For instance, when we collaborated with the SERVIR Global Program's social media campaign revolving the International Women's Day in 2018, it helped promote and highlight women's role within the SERVIR Global network. We believe that dedicated social media campaigns around outreach events and product launches will definitely help in creating a better profile for SERVIR among the public. Despite an overall spurt in the use of social media by individuals, the use of this platform and the web is still at a nascent stage as far as the governments and institutions of the HKH are concerned.

16.8 Documentation: Use Cases to Capture How a Service Is Used

Use cases help illustrate how SERVIR-HKH services—tools, products, data, training, etc.—are being applied in the real world. These use cases help capture the actual use by a particular user and document how a user interfaced with SERVIR-HKH and how its service was utilized, which then leads to tangible, positive outcomes. They help tell the story of a service, its application, and where the impact was either realized or expected, or both. A SERVIR-HKH application/service can have multiple instances of use, and so multiple use cases per institution or user. Use cases are periodically developed in coordination with the users, the

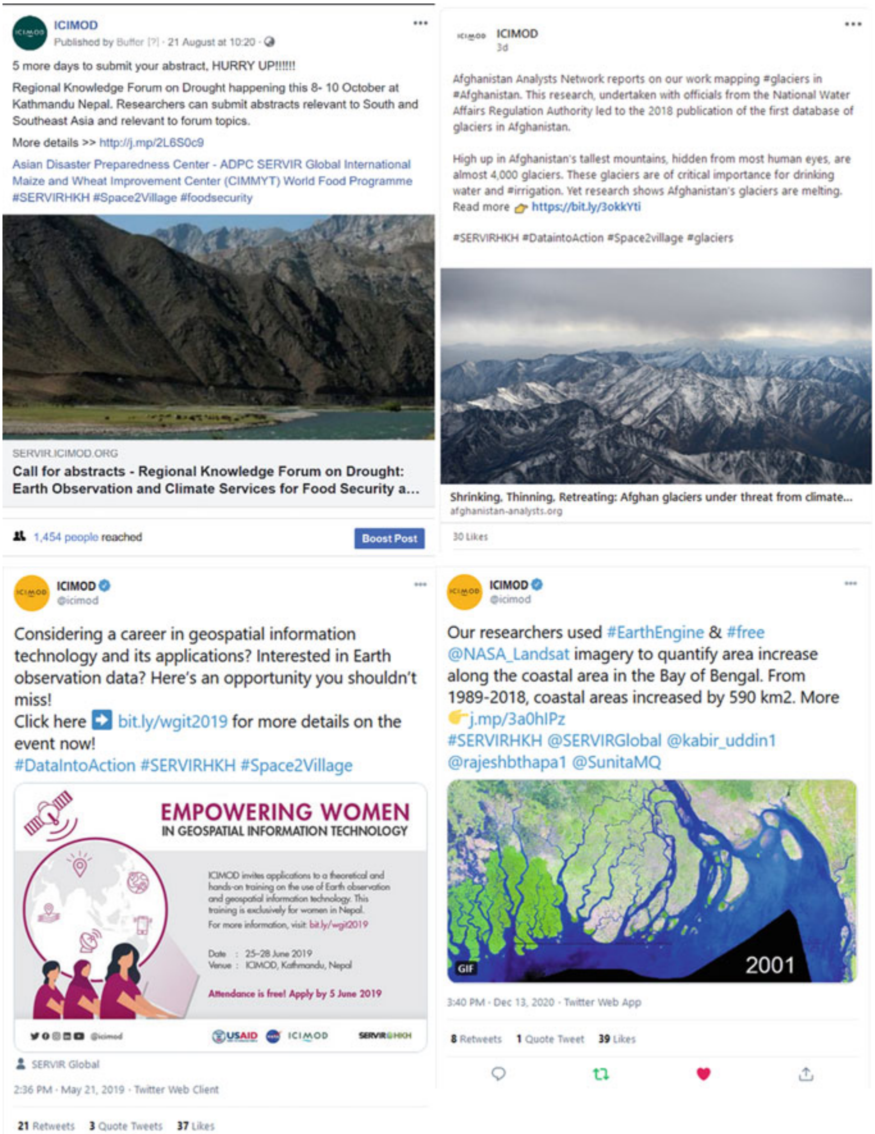

Fig. 16.7 SERVIR-HKH in social media

SERVIR Support team, and the SERVIR Science Coordination Office, and published on the SERVIR Global website and service catalogue. For instance, the use cases of the FFWC in Bangladesh and the Department of Hydrology and Meteorology (DHM) in Nepal have been published, which documented how the two institutions availed of the Streamflow Prediction Tools (Fig. 16.8).

Fig. 16.8 Capturing how the FFWC, Bangladesh uses the Streamflow Prediction Tool to improve upon the accuracy of its flood-forecasting models (https://www.servirglobal.net/Multimedia/Use-Cases/Use-Case_FFWC)

16.9 Regional Knowledge Forums and Global Outreach

A considerable amount of research is being carried out in the HKH region to generate easily accessible, timely, and actionable scientific information to address the adverse impacts of floods, drought, and high-impact weather events. While SERVIR-HKH has been primarily working on developing the applications and services prioritized by its users, other initiatives with a similar mission have been generating a large amount of data and information, and these can complement each other. SERVIR-HKH has realized that when regional platforms review and assess ongoing regional and national practices and policies, it helps in cross-learning and building synergies within and across ICIMOD's regional member countries. In this context, regional knowledge forums and outreach events, organized at yearly intervals, brought together stakeholders from the region and beyond, and held discussions on current developments and challenges in a particular theme of interest; for example, the use of EO information to ameliorate the impacts of drought and water, and weather-induced disasters. These events also served to review the current status of science in the domain.

Some of these events include a "Regional Knowledge Forum on Drought: Earth Observation and Climate Services for Food Security and Agricultural Decision-Making in South Asia and Southeast Asia", organized from 8–10 October 2018 in Kathmandu jointly with the Asian Disaster Preparedness Center (ADPC)/

SERVIR-Mekong and the International Maize and Wheat Improvement Center (CIMMYT); this forum established an expert working group, comprising of representatives from different institutions working on drought early warning systems and agricultural advisory services, to foster regional cooperation on agriculture, drought monitoring, and management. Another was a regional workshop in August 2019 where the RDMOS was unveiled; this was organized by ICIMOD, CIMMYT, and the South Asian Association for Regional Cooperation's (SAARC's) Agriculture Centre in Islamabad, and was attended by policymakers, scientists, and government officials. Similarly, a "Regional Knowledge Forum on Early Warning for Flood and High Impact Weather Events" was organized in October 2019 in Kathmandu to showcase developments in the Streamflow Prediction Tool and the High-Impact Weather Assessment Toolkit (HIWAT); this provided a platform to discuss the challenges associated with the development, implementation, dissemination, and sustained use of information services for water and weather-induced disasters. Besides, SERVIR-HKH, together with SERVIR-Mekong and the NASA SERVIR Science Coordination Office, have regularly organized sessions on EO applications in South and Southeast Asia during the Annual American Geophysical Union (AGU) fall meetings. The AGU event promotes discoveries in Earth and space science that have benefited humanity, and is the biggest gathering of scientists across the globe. It provides a unique opportunity for scientists to present their work and network with the global community. SERVIR-HKH has also been regularly participating in the Group on Earth Observation (GEO) Summit and in the Geospatial World Forum which are global platforms to promote activities on EO/GIT, network with professionals and policymakers, and develop deeper collaborations. Dedicated SERVIR exhibits at these events have been useful in reaching out to larger audiences. SERVIR-HKH has also collaborated with other regional and international initiatives like Asia-Oceania GEO, Global Forest Observations Initiative (GFOI), and SIlvaCarbon, among others, to carry out more

Table 16.3 Key global and regional events organized/participated by SERVIR-HKH to showcase its work

Date/venue	Events
October 2018/ Kathmandu	Regional Knowledge Forum on Drought: Earth Observation and Climate Services for Food Security and Agricultural Decision-making in South Asia and Southeast Asia
October 2019/ Kathmandu	Regional Knowledge Forum on Early Warning for Floods and High-Impact Weather Events
Annual/Different countries	Group on Earth Observation (GEO) Summit
Annual/Different countries	Asia-Oceania GEO Symposium
Annual/Different countries	Geospatial World Forum
Annual/USA	American Geophysical Union (AGU) fall meetings

capacity-building activities in the HKH region. The key global and regional events organized by SERVIR-HKH and those in which it participates regularly are listed in Table 16.3.

16.10 Experiences and Way Forward

The diversity of SERVIR-HKH's user base and the nature of information and services it generates demand a comprehensive communications approach. The Service Planning Toolkit and SERVIR-HKH's KMC Strategy have guided the design of outreach activities and the development of knowledge products and marketing collaterals. Though the strategy provides a broader overview, the knowledge products, and marketing collaterals need to be customized to suit users' needs and contexts which vary at national and local levels.

After receiving comprehensive feedback from the users, the design and implementation of the SERVIR-HKH applications and services underwent changes and were further refined during the development process. We also recognized that marketing collaterals have to be updated frequently to account for these changes. Knowledge products and marketing collaterals undergo a rigorous review process in-house by designers, editors, and country focal persons before being released to the public. The wider SERVIR network, comprising five hubs across the world, have lauded our approach—of bespoke illustrations, success stories, and story maps—at virtual and in-person meetings.

The primary user base of SERVIR-HKH's services consists of information producers and decision makers. We have carried out language localization for some of our services; we also work with our partners to organize consultations, trainings, and outreach events in the vernacular language, and translate the knowledge products into the vernacular language when required. These efforts could be maximized to widen our user base and reach out to more beneficiaries.

While we do invite media persons and agencies to our outreach events and regional fora and pen op-eds in the newspapers, there's a lot more to be done to educate the media in becoming better science communicators and knowledge intermediaries. The decision makers too have to be familiarized with the ways of scientific communication.

Most SERVIR-HKH staff have academic backgrounds in science, technology, engineering, and mathematics (STEM), and their writing style is oriented towards scientific conferences and forums. Therefore, we also prepare posters and social media graphics using simplified infographics to cater to general audiences. However, given the scientific nature of SERVIR-HKH's work, it is difficult to capture and translate the scientific messages accurately to a lay audience.

SERVIR-HKH's digital presence is underpinned through a dedicated SERVIR-HKH website, which serves as the primary channel for data, information, and science applications, as well as for updates on training events and meetings. The news and stories posted on the website help in conveying information to the general public in a timely manner. Ensuring that the information on different science applications are up to date is important as disruptions in data links, server, and core software updates, and internet outages can affect uptime and the functioning of the science applications. User complaints received via the feedback form listed on the SERVIR-HKH website and through conventional emails often alert the team of such problems. Additionally, information about the science applications needs to be periodically updated to account for changes in the focus and scope of these applications. Assigning dedicated human resources to monitor uptime, information accuracy, and relevance, and periodic calendared health checks and information appraisals can be helpful in taking the appropriate measures.

A basic metric of digital engagement is the number of visitors to the website and the number of downloads. We would experience a surge in the number of visitors when a major outreach event is around the corner or when there's an open call for applications, and this number would drop in the weeks that follow. Regular promotional campaigns—via email, social media, and in-person—are important to draw and sustain the attention of more users.

Social media presence is characterized by continuity and a focus on dialogue with the users. Timing and dialogue are important considerations to understand which messaging strategies are most effective in achieving user engagement. The social media landscape is constantly evolving, and brands and institutions are constantly vying to increase their social media presence. However, complying with protocols for institutional clearance while engaging with the media and social media affect timeliness and relevance. What's required is a clear strategy and process for engaging the media and also to respond to comments and feedback on social media.

Information about the actual impact of science communication on policy decisions is rather sparse as it is difficult to study, assess, and attribute how policymakers are affected by scientific information and how they use it. It is almost impossible to know with any certainty that a specific decision made by an individual or a group resulted from a specific encounter with a relevant piece of information (NASEM 2017). SERVIR-HKH has been documenting all references on the use of its data or publications by national governments in their reporting or policy documents. While counting the number of website visits and engagement rates on social media do provide good proxy measures, more robust monitoring and evaluation tools are needed to capture outcomes and impacts. Now, with the Covid-19 pandemic in place and the resultant restrictions on travel and face-to-face meetings, user engagement has shifted more towards virtual engagement, adopting asynchronous modes of communication, and the need to over-communicate. This also means there's a need to reassess the existing modes of knowledge sharing and outreach, as well as user engagement, and that there's an opportunity to invent and adopt new modalities of communication. Ultimately, SERVIR's goal of "Connecting Space to Village" can only be achieved through effective and efficient communication.

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Chapter 17
User Engagement for Sustaining Services

Naina Shakya, Santosh Pathak, Birendra Bajracharya, and Mir A. Matin

17.1 Introduction

"Users' Need First" was one of the significant lessons from the first phase of SERVIR-HKH. There was a disconnect between the cutting-edge technology products that were developed and the specific needs of the users. Thus, SERVIR-HKH needed a way to encourage and involve the users to actively collaborate during the development and rollout of SERVIR's products. SERVIR Global then developed a service planning approach (SPA), shifting the focus from products to comprehensive services that put the users' need first (Chap. 2). Service planning provides a framework for actively engaging the stakeholders and end users, starting from the design of the service to its delivery and adoption by the user. This approach to user engagement improves the quality of the services by addressing user feedback and also builds sustainability into the services from the very beginning.

User engagement has multiple definitions, and there is no single definition that covers the term entirely. Since the last two decades, the human–computer interaction community has become progressively interested in comprehending, designing for, and measuring user engagement with various computer-based features (Hassenzahl and Tractinsky 2006) involving education, gaming, social and news media as well as search applications. User engagement, in the corporate sector, is the degree to which the users find products, services, and processes that are interesting or useful. User engagement depends on the usability of the products and services, the look and feel factor, the usefulness of the information, the scope for interaction and participation of the users, and productivity that reflects the accomplishment of the user's goals (Spacey 2017). Thus, user engagement considers the ability and capacity to engage as well as sustain the engagement (O'Brien

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_17

et al. 2018). The engagement of the user is important because engagement and behavior are implicitly connected to the level of individual interest. For example, the more time a person engages with a product, this means he or she is interested in the product. The task of businesses is to find ways to improve user engagement and to ensure that the user spends more time with the product or service (CodeFuel 2015).

With the primary objectives to promote the applications of geospatial technologies and EO information, SERVIR-HKH works with diverse sets of users which include government agencies, development agencies, research/academic organizations, non-governmental organizations, community-based organizations, and the private sector. For SERVIR-HKH, user engagement is a multifaceted, multi-stakeholder, and multi-country complex process with its challenges as well as opportunities. Systematic engagement with the users is important for a better understanding of the problems and developing solutions to address these problems. In this regard, partnerships with key stakeholders for co-development, ownership as well as for feedback from the broader stakeholders help in the sustainable impact of the services.

SPA (Chap. 2) recommends the engagement of various users in service planning discussions, starting with the identification of problems and culminating in the delivery of products, tools, and services. The user engagement strategy and approach were employed to guide the engagement with the user institutions in order to build long-term mutually beneficial relationships with each user.

This chapter aims to introduce the concept of user engagement in the context of SERVIR-HKH and its execution within the service planning framework; it also dwells on the lessons that have been learnt. The chapter also gives prominence to examples of user engagement case studies as well as to the tools and techniques that have been adopted for successful user engagement. It also describes the insights, achievements, and experiences during the implementation process of the user engagement module in the HKH region.

17.2 User Landscape of SERVIR-HKH

SERVIR defines users as "individuals or institutions that consult SERVIR data, products or tools to fulfill a particular purpose. They can be analysts or decision-makers who are often responsible for communicating to beneficiaries" (Chap. 2, Service Planning Toolkit 2017). The users include mandatory line agencies on the thematic areas such as government ministries and departments, meteorological agencies, and census bureaus; academic and research organizations such as universities and research centers; and larger stakeholders such as subnational offices, extension agents, NGOs, media, relevant donor-funded projects, private-sector associations, and cooperatives. These users can be divided into three main categories: primary users; secondary users, and end users. Below are the descriptions of each of these categories of users.

Primary users

Primary users are organizations with institutional mandates to collect, analyze, and generate data or make policy decisions in a particular service area. They are usually government ministries and departments with which non-binding agreements have been signed, namely: memorandum of understanding (MoU) and letter of intent (LoI). In the case of SERVIR-HKH, while MoUs were signed with ministry-level governmental agencies of Afghanistan, Bangladesh, Nepal, and Pakistan, LoIs were signed with the relevant departments of government agencies, academic institutions, and international development organizations working in these countries. Primary users are the immediate users of a service and are in a position to support the uptake and enhance the development impact of the service by usage and dissemination. SERVIR-HKH collaborated with these users right from the stage of scoping and needs assessment.

Secondary users

The second category of users comprises organizations that are part of the constituency of primary users; they are expected to use the services to support their decision-making process but are not directly involved in data generation or analysis. In this regard, formal agreements with SERVIR-HKH may not be established. However, they are associated through certain service-level activities in terms of reviewing service products, providing inputs for improvements, and also using the products. SERVIR-HKH works with these users directly or through the primary users. These secondary users are in a position to support the uptake and enhance the development impact of a service via usage and dissemination.

End users/beneficiaries

The third category comprises those who will benefit from the use of the services by the primary and secondary users. SERVIR-HKH tries to ensure innovative approaches for enhancing products and services uptake with the end users. End users could also be representatives from under-represented audiences, especially those marginalized by gender, geography, or by access to technology; community-level agencies; researchers; private-sector entities; and identified or potential users, including individuals who are not directly involved in the design process. Their needs and expectations are addressed to the extent possible through the inputs of the primary users who are mainly responsible towards these users. Though these set of users may not have been consulted during the product development process, they are critical in achieving the intended impacts from the service. Thus, through service planning as an inclusive process, creating and delivering customizable solutions to the end users are envisaged in the longer term.

17.3 User Engagement Strategy

The diversity and landscape of the users are constantly changing and this has an impact on how to keep the users engaged. In this context, innovative engagement strategies, plans, and methods are required to be proactively more reachable, inclusive, and versatile than ever before (IGIF 2018). There are a set of processes to ensure that the services and products respond to the needs of the users and/or create new needs. The services and products that SERVIR-HKH develops are intended to support informed decision-making and are to be used by agencies to serve their needs. Therefore, it is important not only to engage the users but also to co-create the products with the users. Each user has his or her own individual priorities, ways of working, and systems, depending on the constituencies they serve. The co-creation process entails open discussions on these priorities and the ways of working in alignment with the product features, user interface, and to ensure that there is a sense of ownership among the users with a greater likelihood of the products and services being used effectively. Therefore, an engagement approach was adopted for a meaningful and fit-for-purpose user engagement and adds value to the products and processes with more connect and sense of ownership.

SERVIR-HKH has in place a comprehensive User Engagement Strategy. This strategy serves as a guiding document for systematically engaging the users through close interactions and has helped in fostering understanding among SERVIR's national, regional, and global partners. This has also helped in the users being at the forefront of technological innovations and has enhanced the value of the products to the users, thereby ensuring that the products are used more appropriately. Furthermore, the strategy explains the user types, levels of engagements, and the tools and techniques that are to be used in developing appropriate platforms for sustained upscaling and enhancement of product uptake.

The User Engagement Strategy is a general plan to achieve effective service-level user engagement at different phases of service planning and design, and to ensure that the services and products are co-designed and co-implemented with the partners. This strategy of SERVIR-HKH is composed of two main parts: the user engagement approach; and the user engagement cycle which includes related activities that can strengthen user engagement.

17.3.1 User Engagement Approach

The user engagement approach of SERVIR-HKH has been adapted from the partnership module of the Partnership Brokers Association (PBA, www.partnershipbrokers.org) which is based on internationally recognized principles, frameworks, and partnership cycles. The approach is grounded in the key principles of diversity, equity, openness, mutual benefit, and courage (ICIMOD 2017).

Diversity means that all the users will have different ideas, unique expertise, knowledge, and institutional culture, which should be embraced for creating new values and innovations. For SERVIR-HKH, it is very important to acknowledge these regional diversities and variations that each user brings, and to use them to build on effective user engagement with the aim of creating new values.

Equity means that all the users are treated equitably, that their voices are heard, and their contributions are valued. For SERVIR-HKH, this means that all the users in the region, irrespective of their size, have an equal right to be heard and to contribute. It means that SERVIR-HKH and the users will each contribute to the partnership from their areas of competence and strength, and will respect and uphold each other's commitments. Where genuine equity exists, the users are much more likely to value and respect each other's contributions.

Openness refers to enabling an environment of transparency. SERVIR-HKH's practices are open and honest in their dealings with the users; they do not intentionally withhold information and they make decisions based on dialogue and mutual understanding. It is all too well known that transparency plays a vital role in building trust, which, in turn, ensures accountability among the users.

Mutual benefit recognizes that different users may be involved in projects/initiatives for different reasons, but all of them are striving towards achieving the same goals. For SERVIR-HKH, it is important to be able to discuss and recognize each user's individual reasons for being involved and ensure that these are met. When mutual benefits exist, there is a greater possibility that the users will continue to engage and look for solutions even in difficult situations. Thereby, services are likely to be much more sustainable.

Courage refers to encouraging users to work together more closely in areas of uncertainty in order to achieve breakthrough results. Equipped with the courage to confront challenging situations and take the user into confidence, SERVIR-HKH will be able to take up new innovations and approaches that can add value to the overall objectives.

17.3.2 User Engagement Cycle

The user engagement cycle (ICIMOD 2017) has been designed along three key stages. The cycle follows a step-by-step process with a series of practical guidelines and procedures for developing, managing, and maintaining user engagement (Fig. 17.1). Each of the steps indicated in the cycle are explained below as well as the related activities.

i. **Needs Assessment**

Stakeholder mapping and consultations

The major activities during the needs assessment phase were stakeholder mapping and holding stakeholder consultation workshops. An important aspect of

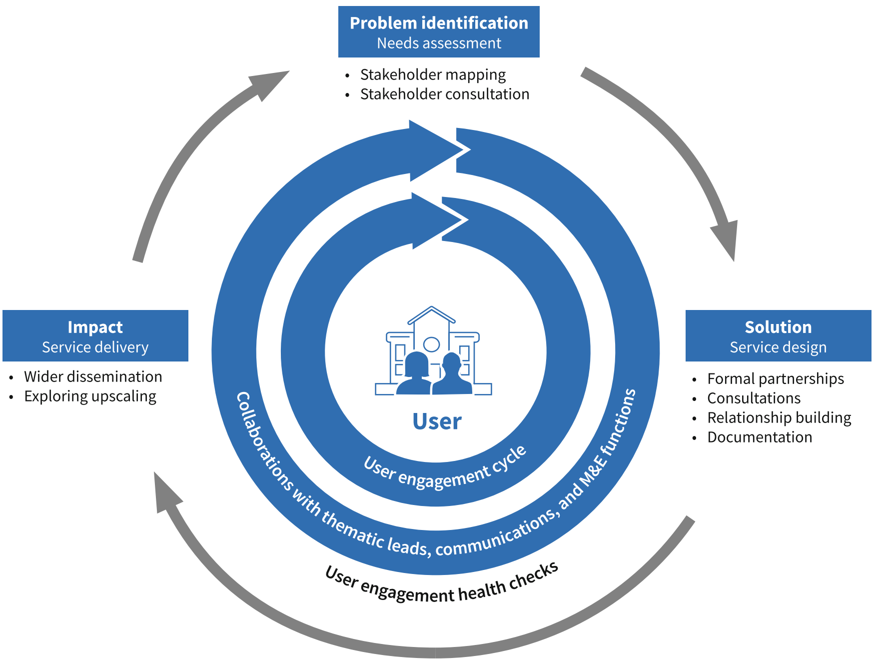

Fig. 17.1 User engagement cycle and activities

stakeholder mapping from the SERVIR perspective is to understand the flow of information, mandates, and functions. As explained in Chap. 2, stakeholder-mapping exercises are conducted in order to understand the user landscape for a particular service area. The stakeholder-mapping exercise helped in the identification of primary and secondary users and beneficiaries. This initial approach entailed scoping and identifying the users through consultation workshops conducted in each country on the relevant thematic areas. Through these exercises, the identification and assessment of potential users, along with their needs, existing gaps, expectations, and possible contributions, were discussed. This exercise involved a wide range of stakeholders in each service area in the target countries. This proved effective in mapping the relevant set of users for further engagement with SERVIR. The workshops were consciously designed to create an environment of open discussion, exchange of information, and negotiations; these also helped in creating a better understanding among the SERVIR-HKH team and its potential partners about the activities that were to be undertaken.

Thus, even if a potential partner had the mandate in a particular service area, there was the need to align goals, objectives, and interests between the potential partner and SERVIR-HKH. In this regard, there were some pertinent questions to be taken into consideration: what would be the complementary contribution of SERVIR-HKH; is there a duplication in effort; and, is the organization willing to take the ownership of the service and continue in a sustainable manner? Then, capacity assessments of the potential partners (Chap. 3) were carried out to identify their capacity-building needs in terms of human resources, data-generation/sharing policies and practices, and the mandated services provided to the end users.

ii. **Service design**

During the service design phase, user engagement involved a number of activities that included establishing formal partnerships with the primary stakeholders, holding consultation workshops for users' orientation and feedback, carrying out regular interactions for strengthening relationships, and preparing documents.

Forming partnerships

In the context of SERVIR service planning, the primary and secondary users that were identified were mainly government ministries, departments/subnational offices, and other relevant organizations. The discussions with these government agencies veered around co-developing the applications with support mainly for technology transfer and capacity-building activities. Thus, to develop a sense of ownership and strengthen the commitment of these primary users, partnership instruments such as MoU and LoI were designed. The signing of such an agreement helped in building a strong partnership—keeping in mind the principles of equity, transparency, and mutual respect. The MoU was signed for agreement on broader areas of institutional collaboration, while the LoI was a non-binding partnership instrument without financial obligations to either organization in order to establish strategic alliance in the areas of mutual interest, especially in the areas of knowledge sharing and research. The overall agreement outlined the alliance in joint activities and listed out the complementary values that each partner would bring to the partnership. The partnership instruments thus expedited and formalized the processes of user engagement and also helped to outline mutual commitment and responsibilities. The partnership landscape of SERVIR-HKH in terms of the service areas is presented in Fig. 17.2.

Consultation workshops for user orientation and feedback

Focused service-wise workshops were conducted in each country for orientation and discussions on the methodologies, outputs, and design aspects of the products and services. The workshops were tailor-designed to initiate discussions and to brainstorm in order to have clarity on the co-development of the service products. Discussions were also held on ToC and the User Engagement Strategy and approach. These workshops helped to create a common understanding among all the stakeholders so as to facilitate better and effective exchange of ideas and knowledge, and to get feedback on the service design. The workshops also contributed to strengthening the SERVIR network and presence in the member countries and fostered collaboration in the implementation of the activities. Overall, these workshops helped the SERVIR-HKH team to arrive at a better understanding about its roles and responsibilities as well as about the expectations of the users and thereby agree on a set of joint activities.

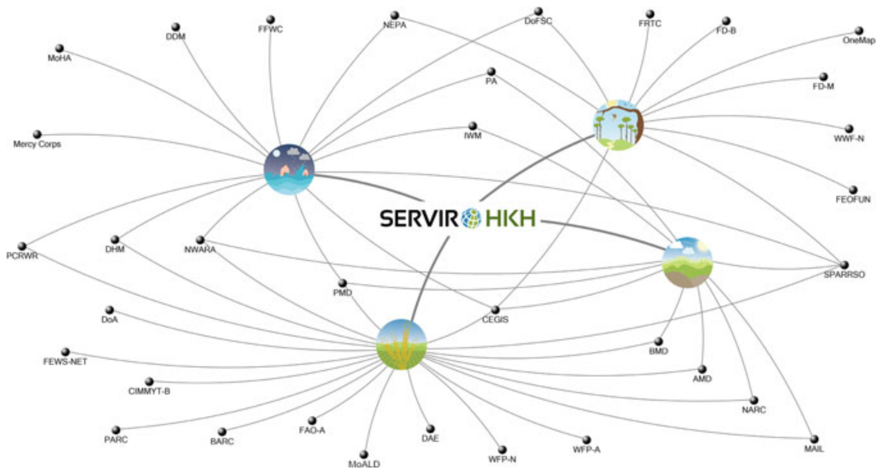

Fig. 17.2 Consolidated user landscape according to **a** service area, **b** country. *Note* Afghanistan Meteorological Department (AMD), Bangladesh Meteorological Department (BMD), Bangladesh Agricultural Research Council (BARC), Bangladesh Space Research and Remote Sensing Organization (SPARRSO); Centre for Environmental and Geographic Information Services (CEGIS), International Maize and Wheat Improvement Center (CIMMYT); Department of Agriculture (DoA); Department of Agricultural Extension (DAE); Department of Hydrology and Meteorology (DHM); Department of Forests and Soil Conservation (DoFSC); Department of Disaster Management (DDM); Famine Early Warning Systems Network (FEWS-NET); Food and Agriculture Organization (FAO)-Afghanistan; Flood Forecasting and Warning Centre (FFWC); Forest Department (FD); Forest Research and Training Center (FRTC); Federation of Community Forestry Users Nepal (FECOFUN); BUET—Institute of Water and Flood Management (IWFM); Institute of Water Modelling (IWM); Jahangirnagar University—Institute of Remote Sensing (JU-IRS); Kabul University (KU); Local Government Engineering Department (LGED); Mercy Corps (MC); Ministry of Agriculture, Irrigation and Livestock (MAIL); Ministry of Agriculture and Livestock Development (MoALD); Ministry of Home Affairs (MoHA); National Water Affairs Regulation Authority (NWARA); National Environmental Protection Agency (NEPA); Nangarhar University (NU); Nepal Agricultural Research Council (NARC); Practical Action (PA); Pakistan Meteorological Department (PMD); Pakistan Council of Research in Water Resources (PCRWR); Pakistan Agriculture Research Council (PARC); World Food Programme (WFP); World Wide Fund (WWF)

Relationship-building interactions

Relationship-building activities were conducted with potential partners and users through meetings and discussions, followed by negotiations and planning with these organizations for mutual consent, and finally developing an appropriate partnership instrument/agreement to formalize the partnership. It was important to lay emphasis on the fact that each of these organizations added value and that there would be clear benefits for these organizations; it was also emphasized that there would be minimal institutional risks and that the overall aim was to aid effective decision-making and support the stakeholders.

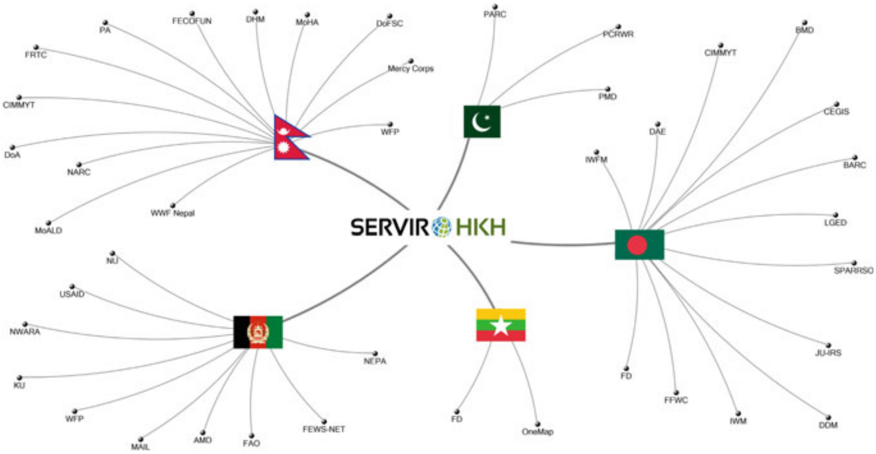

Fig. 17.2 (continued)

From the very beginning, SERVIR-HKH focused on strengthening its engagement with the users to establish mutually beneficial partnerships instead of just an alliance for building a product. Therefore, the focus was on having open communication through regular meetings and interactions with the users. The purpose of the meetings was to get to know each other better, discuss mutual interests in terms of the overall objective of SERVIR, to understand individual benefits, explore the value-addition aspect, and clarify on the expectations and contributions. This process provided an ideal opportunity to help build a strong partnership through the principles of openness, mutual respect, and courage to accept the unknowns of complex partnership issues to boldly address them for achieving breakthrough results.

In the case of ongoing partnerships, these meetings reviewed the progress and follow-up actions so as to evaluate whether the targets had been achieved. At the end of each meeting, the briefs of the discussions were shared with all the participants. All of these interactions helped in arriving at a better understanding about the problems, challenges, and opportunities. This means of acknowledging successes and failures will help pave the way for better planning of the future course of action.

Documentation

Documentation is not merely about recording the evidence of activities but also about references that can help in tracking and updating the activities. As part of an effective user engagement process, SERVIR-HKH has focused on proper documentation of key user engagement activities, such as in the form of workshop reports, meeting summaries with key action points, and agreement papers. It goes without saying that good documentation makes it easier to track the progress of a particular activity and helps in following up on updates on each service product.

iii. **Service delivery**

Wider dissemination and uptake

Once the services segment was completed, dissemination workshops were held for the wider user community. Also, there was a seeking of additional partners and potential beneficiaries who could take up the services and ensure their sustainable use. Multi-stakeholder workshops were also conducted in order to extensively disseminate the service products and to strengthen user engagement for wider adoption and use of the services. Aligned with the service planning approach, the objective of these workshops was to work together with the users and a wider range of stakeholders, thereby enabling the sharing of the various SERVIR-HKH service products and also building awareness. The workshops also helped ensure that the services and products were of interest and that there were potential beneficiaries who would use and upscale these products. Besides, the workshops and learning sessions were platforms for sharing experiences and ideas. This provided a great opportunity for cross-learning among the users.

The final set of workshops also hoped to receive feedback on the sustainable use of the service products beyond the sphere of SERVIR-HKH and on constructive inputs for the next phase. An important objective of the meetings and discussions was also to explore potential for outscaling and uptake from a wider range of relevant stakeholders, including professionals and researchers from government agencies, the private sector, academia, NGOs, and other institutions engaged in providing similar services. The process also considered the interest and engagement of the users beyond the life of SERVIR-HKH. Besides, the dissemination workshops and interactions with the users sought how to increase user engagement and capacity building, keeping in mind the aspect of gender and social inclusion as per the mandate of ToC. Targeted communication products were also designed and distributed to increase the outreach and visibility of SERVIR-HKH in the region and beyond.

17.3.3 Crosscutting Activities

Integration with service support functions

As part of the user engagement process, close integration with the other service support functions was equally important. These functions included monitoring and evaluation (Chap. 18), the aspect of gender (Chap. 15), communication (Chap. 16), and capacity building (Chap. 14). Thus, the user engagement process ensured that these functions were in sync with the service planning approach. This was executed through an integrated approach while designing and conducting workshops and training events with the users; there were also regular internal meetings to share progress/updates and discuss the challenges. The institutionalization of the user engagement process at the service level was undertaken with all the primary users of SERVIR-HKH as the activities were co-implemented in each service area.

User engagement health check

As part of the strengthening of the user engagement process, reviews were also conducted on the state of this engagement process. These health checks were not standalone activities but were strategically integrated into the national and regional workshops with the users, focusing on a specific product or a service area. These were part of an annual process to review the user engagement procedure and the overall experience. This helped to ensure that all the users understood each other's difficulties so as to address them in the best way possible. The key questions that were asked were: how is the user engagement proceeding; what has worked well and what has not; what needs to be done differently; and, what can be collectively done to address the problems, if any?

These health-check exercises were basically in the form of half- or one-day workshops with modules of user engagement discussions/group exercises to not only discuss and resolve any issues but also to look at the benefits and costs of such engagements and what could be changed to make them more effective and efficient. An annual health check was also conducted for each of the service areas. Besides, discussions were held on identifying the areas that needed revisions. At these discussions, the users expressed their opinions on the need for improvements; they stated that there should be more frequent feedback and that there should be a review of the implementation timeline for the co-development and co-implementation processes based on emerging needs. Some of the major recommendations then became part of user engagement agreements. These health checks were an unusual exercise for the users, but much appreciated. Similarly, as part of the strategic review and planning process of SERVIR-HKH, a SWOT analysis was conducted involving all the primary users. These reviews facilitated a close working relationship with the users and helped in identifying the strengths and weaknesses of the overall engagement process. While the health checks were more focused on improving engagement with each user, the SWOT analysis was more focused on an overall review of SERVIR-HKH.

The extent of engagement with the primary, secondary, and end users varied as the roles were different. Figure 17.3 shows the intimacy matrix for different users based on the closeness of relation r as well as the level of engagement. This matrix came about after a consultation process with different users (Chap. 3). "Intimacy" here refers to the intensity of the engagement with the users. While SERVIR-HKH ensured that all users were duly consulted, the intensive procedures of co-design, co-creation, and co-implementation were undertaken with the primary users. The matrix was created to develop an understanding about the different levels of users and about the opportunities to engage with them. This matrix provides a clearer understanding about each type of user and the strategy required to engage with each one of them.

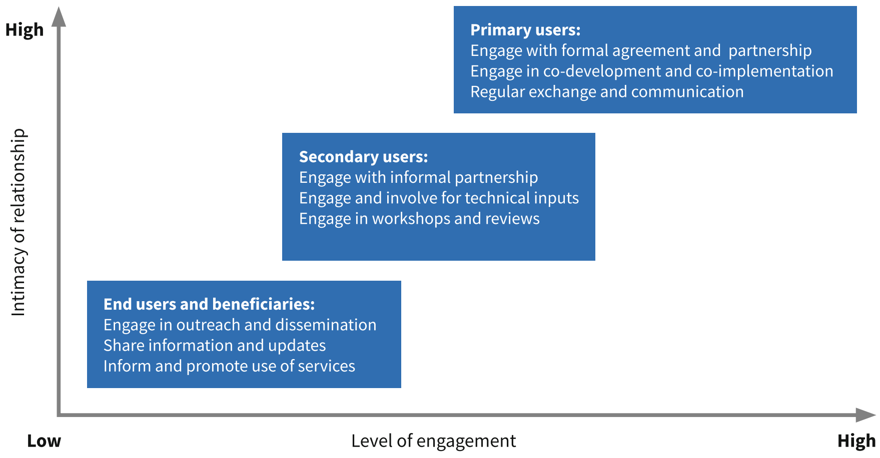

Fig. 17.3 User intimacy matrix

17.4 User Engagement Experiences from SERVIR-HKH: Key Takeaways

In the decade-long implementation process of SERVIR-HKH, user engagement has evolved significantly from the first phase to the second phase. Although SERVIR-HKH started with stakeholder consultations and capacity needs assessments, a systematic user engagement approach was only adopted in the second phase with the development of the service planning approach for use across the SERVIR hubs. With this approach, there has been a significant focus on sustainability and ownership of the services. SERVIR-HKH has been successful in building more sustainable partnerships by establishing formal collaborations where there's a clear agreement on the roles and responsibilities of all those who are involved.

The following section encapsulates the achievements, challenges, and lessons of the whole SERVIR-HKH experience.

Effective engagement within the internal team

The complexity of SERVIR-HKH lies not just externally but also internally between the various teams of experts that provide technical and service support functions. Since SERVIR-HKH works on areas ranging from agriculture, ecosystems, and water resources, to disasters and weather and climate, there is involvement of multidisciplinary professionals in service design and delivery. Moreover, capacity building, gender equality, and monitoring and evaluation are key components of each service. Therefore, regular meetings, internal communications, team-building workshops, and other such exercises were part of the process to strengthen the overall SERVIR-HKH team. Such exercises helped in developing a common understanding and bringing uniformity among the SERVIR-HKH team members while interacting with the partners. They also helped to increase the team synergy and efficiency because of better coordination.

Every user has its own strengths and challenges

When a service is successfully implemented with a user, it doesn't mean the same will happen with the others as well. Each user has its own set of unique issues and strengths, and therefore, the engagement should be focused on addressing the problems and complementing the strengths. Mechanisms such as SWOT analysis, scoping, and consultation workshops are helpful in understanding these aspects. Having the "right" or "fit-for-purpose" partner is critical, so a lot of effort has to go into the selection of partners. This means following the due diligence process that involves scoping and identifying the users through stakeholder mapping, consultations, and needs assessment. All of these help in forming a better understanding about the users and their capacities, and about their interests as well as expectations. SERVIR-HKH used these processes and they were really helpful in getting to know about the perspectives of the users in terms of the challenges, opportunities, and their level of satisfaction. By knowing more about the users and their expectations, the path became smoother in co-developing and co-implementing the services.

Deepening the engagement

For an initiative like SERVIR-HKH or a similar one that focuses on co-design and co-development, it is important to lay emphasis on continuous and close engagement with the users. This requires constant communication, consultations, and meetings. Also, there should be formal agreements (whether legally binding or not) with the users, especially when it comes to working with government users wherein the bureaucratic structures often cause the transfer of some key focal persons; without any written agreements/documents, it is often difficult to follow up on a project once the focal person gets transferred. This also means redundance in terms of sharing information and it even can bring a project to a standstill. In such situations, having an agreement is really helpful in that it reminds the focal person about the agreement and the commitment he or she had made. However, it is important to draft this agreement in a way that it not only reflects the obligations but also the roles. SERVIR-HKH has had such agreements with 15 users and these were instrumental in building a common understanding and clarity about mutual expectations.

It is also important to understand that negotiations take time. SERVIR-HKH spent a good amount of the initial project period to identify the key implementing partners and to negotiate on possible collaborations. These negotiations can be time-consuming and frustrating at times, especially with government agencies that have their own processes and procedures. It took over two years with one of the partners in Nepal and three years with another partner in Bangladesh to sign MoUs with SERVIR-HKH. However, this is a very important step to bring mutual clarity around the roles and contributions from all the engaged users, and the collaborations with FRTC and BMD are seen as successes of SERVIR-HKH.

Thinking together and clarifying expectations

Co-design and co-implementation demand a lot of collective effort on the part of the stakeholders and users, especially when the applications are to be ultimately owned by the users; so, a lot of effort and resources need to be invested on consultations, meetings, and workshops. During the implementation phases of SERVIR-HKH, a lot of such physical and virtual events were conducted. And through this constant process of communication and sharing of experiences, there came about a clarity on the expectations, thereby increasing mutual trust in the partnership. It is also important to understand that partnerships will be successful only if there is mutual benefit. SERVIR-HKH often received one common question from most of the users: “What will we get out of this partnership?” Working together and exploring benefits from partnerships are really important to maintain consistent interest among the users. This was possible with the implementation of the engagement approach and the engagement cycle, which really helped in forging partnerships. This also helped in developing a common understating and clarifying expectations from each other. The key principles of diversity, equity, openness, mutual benefit, and courage helped the partners to engage and communicate in a more effective way.

Unique situations with partners

SERVIR-HKH works in five countries, mainly with the mandated government agencies as the implementing partners. The engagements in these different countries are also guided by varying policies, institutional setups, human resources, and IT capacities. Therefore, a single approach is not suitable for all kinds of partnerships, and the engagement process with each of the partners requires specific considerations. What is more important is the development of a broader strategy and work around each separate partnership. The patterns of user engagement may come across as unpredictable and unexpected at times. A case from Afghanistan is worth mentioning here. Afghanistan’s MAIL is a key partner of SERVIR-HKH. Following the initial needs assessment process, wheat-area mapping was expressed as a priority of the country and SERVIR-HKH was requested for its support. Responding to the need, SERVIR developed a methodology together with NASA for in-season wheat mapping using both optical and SAR images on the GEE platform. During the co-development process, SERVIR-HKH trained the MAIL staff on the methodology and the tools. However, by the time the results were being finalized, the official mandate of wheat mapping was transferred from MAIL to the National Statistic and Information Authority (NSIA) and all the staff trained by SERVIR-HKH left MAIL to join other institutions.

Investment in human resources

It is ultimately the human resources who will be ensuring the quality of work and helping to deliver, and it has no substitute. Therefore, it is always critical to invest in human resources and improve their capacity and skills. Particularly in the case of SERVIR-HKH, which is heavy on science and technology, it is important to ensure that the human resources have the required knowledge and are on par with the updates. The higher the level of ownership and satisfaction among the human resources, the higher the effectiveness and innovations in the implementation of a project. In this context, SERVIR-HKH accords high priority to training the staff of the partner organizations, especially via on-the-job trainings. This has been an effective and rewarding process as the capacity of these staffs has been enhanced and now they conduct such trainings to other beneficiaries independently. One such impact was when SERVIR-HKH conducted a training on "Remote Sensing & Geographical Information System for Water Resource Management" to representatives from Kabul University. Subsequently, the professors from this university independently conducted this training to a wider group of beneficiaries in Afghanistan; this was also included as part of a course in the university. While such an approach builds the confidence of the staff on the use of tools and technologies, this also helps in building inter-personal relations among partner organizations and SERVIR-HKH.

Project is what partnership delivers

Often, while implementing projects, the focus is around output, outcome, and successful closure. In that process, very often, one tends to forget that the success of a project depends on the success of partnerships. Right from the beginning, enough attention should be paid to selecting the right user, establishing good relations with the user institutions, and then managing and maintaining these relationships. It's ultimately mutual trust that delivers a successful project.

Learn to listen to "no" and say 'no" when needed

One of the lessons learnt has been that one has to be prepared to listen to negative feedback from the user. Partner institutions may not always agree with all the procedures of a project; they may even walk out of the project. So, it's important to be prepared for such surprises and work around a thorny issue to find solutions or alternatives. At times, it is also important to say "no" when the user expectations are beyond a project's mandate. For the sake of transparency, saying "no" is equally important as saying "yes", but both have to be backed up with the right reasons.

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Chapter 18
Approach and Process for Effective Planning, Monitoring, and Evaluation

Lalu Maya Kadel, Farid Ahmad, and Ganesh Bhattarai

18.1 Introduction

The use of Earth observation (EO) information and geospatial information technologies (GIT) for evidence-based decision making is a growing opportunity because of open access and increased availability of data. The services from EO have a significant impact on all aspects of everyday life and were recognized at the 2018 United Nations World Geospatial Information Congress for their utility in social, economic, and environmental development (Sheldon et al. 2018). It is a cost-effective solution for advanced understanding of both natural and human-induced global or regional changes through real-time monitoring data. The use of EO and GIT aims at improving understanding about complex environmental and social interactions and enables decision making based on scientific evidence, thus helping in enhancing the well-being and livelihood of the people (Leibrand 2019).

The relevance of science and technology to the HKH region is even higher because of the difficult terrain; the region is also undergoing rapid changes driven by stressors such as climate change and human conflicts, and factors like globalization, infrastructure development, migration, tourism, and urbanization (Sharma et al. 2019). It also faces a data gap that hinders the overall assessment of the region (IPCC 2007; Singh et al. 2011). ICIMOD, therefore, has been working as a SERVIR hub to leverage EO science and GIT toward the region's development since 2010 (Chap. 1). The SERVIR-HKH program aims to strengthen the capacity of the member countries to incorporate EO information and GIT into development decision making in order to address complex problems. The SERVIR-HKH hub works with diverse partners from local, regional and global levels, and each of them have their own priorities and interests. More than science, the issues are geopolitical at the HKH front. Further, socioeconomic issues strongly prevail in the region,

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_18

influencing lives and livelihoods. Understanding these complexities is essential in order to answer some important questions regarding the successful implementation of the SERVIR program and achieving its objective. These questions are as follows:

- What motivates the stakeholders to use EO and GIT in decision-making?
- What hinders them to promote these applications?
- Who should be engaged and why in the process of creating positive change?

Monitoring and evaluation (M&E) can, but does not always answer these questions. Traditional M&E generally uses the logical framework approach which describes the relationship between different components of a program but does not take into account the emerging needs, processes, and results when the context is uncertain to deal with (James 2011). To answer difficult questions, there should be in-depth understanding of complexities; the problem with traditional M&E in dealing with a complex program is that it does not pay enough attention to the change process that unfolds in the midterm; this is an obstacle to achieving long-term goals (Weiss 1995).

On the other hand, modern M&E approaches such as theory of change (ToC) and participatory impact pathway analysis (PIPA) are aware of the complexities, bring stakeholders together, and address the difficult questions that manage large, complex programs. Harnessing complexity requires close observations and interactions at different levels (Douthwaite et al. 2020). The approach promotes collective understanding, reviews, reflections, and adaptive management practices in the SERVIR program.

This chapter carries out an after-action review of the deployment and implementation experiences of SERVIR-HKH and its M&E system that was aware of all the complexities involved; so that many others can learn and adopt such approaches in implementing their programs.

18.2 The Planning, Monitoring, and Evaluation Approach

18.2.1 Theory of Change and Participatory Impact Pathway Analysis

ToC and PIPA are innovative approaches that are being increasingly used to understand the complexity of a program where the desired changes are uncertain (Isabel 2012; Alvarez et al. 2010). According to Davies (2012), ToC is the description of a sequence of events that is expected to lead to a particular desired outcome. From that perspective, ToC helps the relevant practitioners to gain a better understanding about the pathways of change that lead to outcomes and impacts which are often nonlinear and complex. ToC is about the central processes or drivers—such as psychological, social, physical, or economic—through which change comes about in individuals, groups, or communities; this could derive from a formal research-based theory or an unstated, tacit understanding about how things work (Funnell and Rogers 2011).

PIPA in SERVIR-HKH involves an actor-based approach bringing together different stakeholders who are also users of EO products and services; they then develop a collective understanding about the project-impact pathways, and the underlying assumptions of change. ToC adds to an impact pathway by describing the causal assumptions behind the links in the pathway—meaning, what has to happen for the causal linkages to be realized (Mayne and Johnson 2015).

By applying these approaches in planning, monitoring, and evaluation (PM&E), SERVIR-HKH aims for a better understanding of and harnessing of the complexity of the program for navigating change toward outcomes and impacts. Ensuring the adoption and use of EO services for societal benefit is the major objective; societal benefit is obtained when any support has a meaningful impact on the well-being of society (Giovannini et al. 2011), and it can be measured (Bornmann 2012). Result-oriented PM&E focuses on achievements and guarantees that resource allocation and planning are closely tied up with the outcomes and impacts rather than inputs and activities. Comparing what we achieve with what we wanted to achieve provides an opportunity to reflect and learn. It also helps policy and decision makers to demonstrate the impact of a given intervention or policy (Kusek and Rist 2004).

18.2.2 Implementation Framework

The implementation of a framework walks along the project cycle, starting at the design of ToC (Fig. 18.1, left). The use of ToC and PIPA in PM&E along the project cycle aims to facilitate three key functions: accountability, learning, and adaptive management (Fig. 18.1, right). These three functions are interlinked with each other for navigating change in any program or project. The framework shows how the PM&E system (left, outer circle) is based on ToC and how PIPA supports the program cycle (left, inner circle) in terms of the three key functions (right). The implementation of the framework aims at navigating change beyond EO products toward impact for adoption and use of services for societal benefit.

Accountability in development may refer to the obligations of the partners to act according to clearly defined responsibilities, roles, and performance expectations, often with respect to the prudent use of resources (OECD 2002). Result-oriented M&E helps to collect evidence and demonstrates whether results have been achieved and also justifies value for money, while performance data can be collected at different levels of a program or project's result hierarchy.

Learning as a function of result-oriented M&E is drawn especially through the assessment of the response to a particular policy, program, or project. M&E also involves the wider context of knowledge management as an element of organizational learning and one that strengthens performance (Adrien et al. 2008).

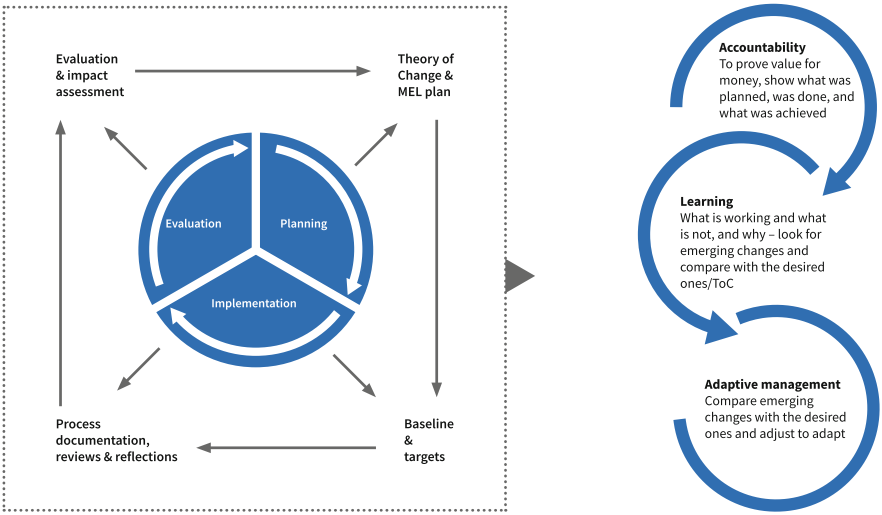

Fig. 18.1 Framework for planning, monitoring, and evaluation

In this regard, adaptive management helps decision makers or managers to respond to an emerging situation, especially in a complex program, to achieve the desired impacts. M&E provides an opportunity to compare the emerging changes with the desired ones and to reflect on learnings and make adjustment in plans. Thus, adaptive management helps to choose the right path, but the goal remains the same. Knowing the path and the destination also guide us in following the more important path (Örtengren 2016).

18.3 Implementation Process

The implementation of the framework in our model followed eight steps in a broader three-phase project cycle (Fig. 18.2). The planning phase began with PIPA for developing the program's ToC and the plan for a monitoring, evaluation, and learning (MEL). The implementation of the plan involved the capacity building of the staff on MEL, based on ToC and process documentation. After a while of the implementation process, the remaining steps began. Reality checks, assessments, and evaluations were carried out, along with documentation of the evidence of change. Then, the progress was periodically reported in order to address the information needs of the stakeholders. Later, learning syntheses, reviews, and reflections were carried out to facilitate learning among the stakeholders. Finally, based on the lessons learnt from M&E, the plans were adjusted or revised according to ToC.

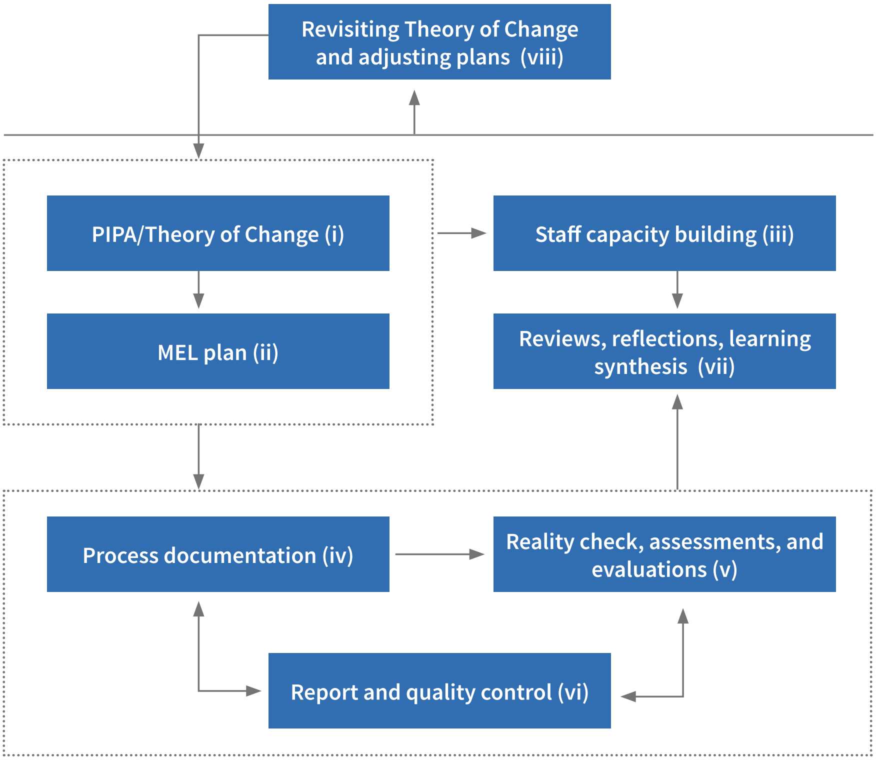

Fig. 18.2 Implementation process of PM&E framework

The aspect of gender has been considered across the PM&E framework as a part of the attempt to mainstream gender and social inclusion in EO and GIT applications and services. We adopted a seven-step framework (Kadel et al. 2017) in the process of project cycle management and encouraged for gender focus right from the beginning at design and planning.

18.3.1 Participatory Impact Pathway Analysis

PIPA was the first step in the PM&E cycle which began with country consultations workshop attended by diverse stakeholders. PIPA is a forward-looking approach built on the past experiences of the stakeholders and provided an opportunity to develop clarity and collective understanding about the program in terms of ToC and performance indicators. The stakeholders systematically followed the seven steps (Fig. 18.3) to come up with a gender-responsive ToC and performance indicators which provided a good basis for program implementation, monitoring, and evaluation.

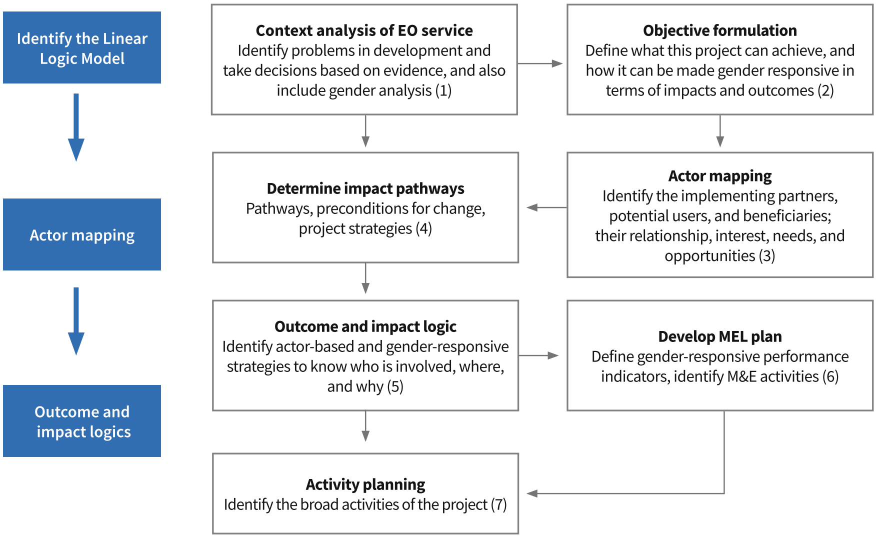

Fig. 18.3 PIPA process followed in SERVIR-HKH program

Both the process and products are equally important in PIPA. The process provides the opportunity for different stakeholders which are also users of EO products and services to come together and develop a collective understanding about the project's impact pathways and the underlying assumptions of change. These assumptions are made explicit through network maps and outcome and impact logic models. The definition of success criteria is based on the indicators that have been identified for monitoring. As for the products, they provide a good basis for program implementation, monitoring, evaluation, and learning. The ToC that was initially developed was not expected to be perfect, but it gradually improved as the understanding evolved. Therefore, once ToC is developed, it is considered as a living document. And the PIPA and ToC concepts were also operationalized at the service level in order to dive deep into the thematic context and develop a collective understanding about the service among the stakeholders.

SERVIR-HKH Theory of Change

In 2014, SERVIR-HKH developed a ToC for the first time for an ongoing project in order to revisit its outcome trajectories. The project team came together at PIPA workshop, reflected on their tasks and achievements about what had worked and what had not and discussed revised outcome trajectories based on the learnings. The ToC was then revised several times in order to simplify it. Figure 18.4 is the simple version of SERVIR-HKH's ToC.

SERVIR-HKH has adopted three interconnected pathways to create an impact: awareness and access, capacity building in cutting-edge EO and GIT applications and provisioning of data tools, applications, and services. The awareness and access

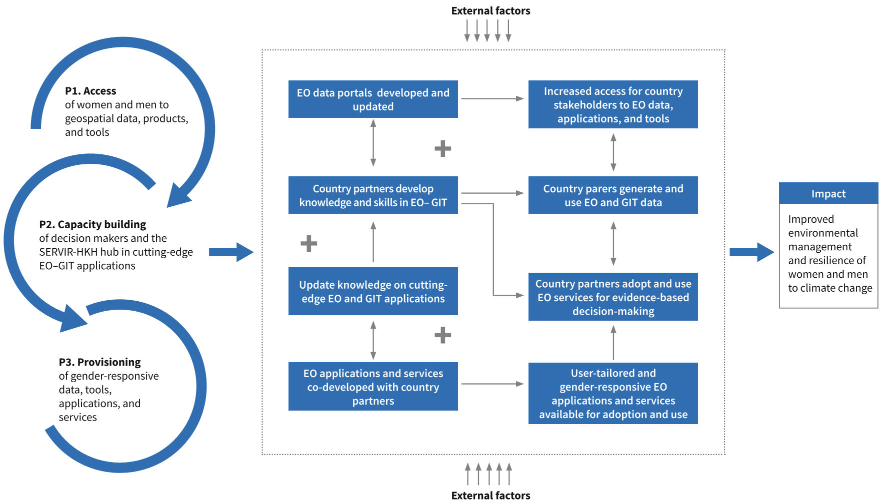

Fig. 18.4 Theory of change of SERVIR-HKH

pathway helped the country partners to increase their access to EO data, applications, and tools; this was enabled by awareness about open access to already available data, developing data portals, improved networks, and sharing mechanisms. The capacity pathway enabled in updating a particular hub's knowledge on cutting-edge EO and GIT applications, thereby transferring the same to the regional member countries. Both women and men were part of this process. These two pathways also built synergy with the third pathway to co-develop user-tailored and gender-responsive EO services. The immediate results of the three pathways led to the applications and services that were developed and tailored to the needs of users which increased adoption and use of EO and GIT applications for evidence-based decision making. Ultimately, the adoption and use at scale would lead to improved environmental management and resilience to climate change.

Actor analysis plays a big role in creating a better understanding about the pathways and makes them explicit by striking out all the assumptions. Understanding how this logic works is crucial in order to stabilize or amplify the beneficial outcome trajectories for achieving the expected change, this was a continuous process during the implementation of the program. When clarity was achieved about the ToC, the stakeholders were in a better position to discuss how the program would be monitored or measured. These discussions led to identifying the performance indicators and due consideration was given to make them gender responsive.

18.3.2 Developing a Plan for Monitoring and Evaluation

M&E depends on efficient planning and clarity about what is being monitored (Simister and Smith 2010). The indicators identified in the first step were further explained or defined for everyone's understanding about what kind of data would be collected and why. Agreement was also reached on M&E activities. Thus, the development of the MEL plan was completed in two steps: preparation of indicator reference sheet and developing the M&E activity plan.

The indicator reference sheet covered details about indicator data, so as to ensure quality and consistency in data collection, compilation, analysis, and use. To guide this process, a standard format was developed which covered important elements like definition, data disaggregation, baseline, target, source of information, the data collection method, frequency of data collection, responsibilities, analysis, and use. The aim of tracking results and measuring change was that the managers would be held more accountable and responsible for achieving results beyond the application or service development. Besides, wherever possible, the setting of gender-disaggregated target was encouraged.

The timely planning of MEL activities was another important part, which is often neglected in practice. This not only ensured budgetary control but also provided enough time to prepare for the implementation of important activities. Systematically planned M&E functions are more effective as they help in timely execution and retain focus. Apart from the factor of indicator data, periodic reviews, assessments, evaluations, learning synthesis, and revision of ToC are important for accountability and adaptive management.

18.3.3 Orientation and Building Staff Capacity

To ensure the adoption and use of EO-based solutions for societal benefit, the managers and data scientists in SERVIR-HKH are expected to think beyond the EO applications. While the staff involved in this program are experts in their subject, they had not been trained in approaches like results-based management (RBM). Thus, the participatory process used for PM&E and M&E trainings, refresher workshops, reviews, reflections, and guidelines helped to build their capacity in RBM. At the monthly staff meetings, M&E was part of the discussion agenda which helped to maintain a continuous focus on this function. The M&E guidelines were also simplified for the benefit of non-M&E professionals.

18.3.4 Process Documentation

While moving to the implementation phase, process documentation became a priority. Process data were important for monitoring the targets and tracking the results. An online event database system was set up for systematic collection, compilation, and analysis of progress data. A standard data collection format was established which could also support data disaggregation. This system has also helped in addressing the problem of duplication.

Besides, pre- and post-training assessment tools were used which helped in making the necessary adjustments in content and method, so as to best fit the participants. While the pre-training assessment mechanism solved for the management the prickly issue of selecting the right candidate, the post-training assessment mechanism paved the way for follow-up actions that needed to be taken to achieve the outcomes envisaged by the ToC.

18.3.5 Reality Checks and Gathering Evidence

After a while into the implementation stage, the partners and stakeholders were expected to respond to the project activities. Both formal and informal processes were used to assess the emerging situation and measure the changes. Knowing whether the targeted stakeholders were adopting and using EO and GIT in decision making or not, and why, helped the managers and the data scientists to adapt to the emerging situation.

Formal tools were used to validate the information collected through the informal process and also to address the information gaps. Tracer studies were conducted to know whether the trainees were using the knowledge and skills acquired at the trainings. This helped in assessing the relevance and effectiveness of the training programs. Besides, periodic assessments were carried out on the organizational capacity levels of the different countries. A post approach to revisiting impact pathways was also adopted, so that the stakeholders could collectively assess as to what was working and what was not. Further, using the ToC, evaluations were carried out to measure the success or failure rate of each EO service. And be it success or failure, all of it has been documented.

The informal process was adopted more at the individual level of EO professionals. After a certain duration of implementation, they were able to closely observe the emergent and expected changes. This also helped them in reflecting on their work to see whether it had made any difference to the overall scheme of things. As for the gender aspect, both formal and informal processes addressed the area.

Box 1. FFWC Bangladesh taking ownership of strengthening FEWS
As a result of a series of trainings, the engineers at the flood forecasting and warning center (FFWC) of Bangladesh have developed a better understanding of the streamflow of upstream rivers, thereby significantly improving their capacity to deliver better and more effective flood warnings. They are now in a position to calibrate and validate model outputs with the data collected during the 2018 floods.

In order to stabilize and amplify this outcome trajectory of strengthened flood early warning system, SERVIR-HKH has been working closely with the FFWC engineers; this has also helped to strengthen these engineers' capacity. Besides, enough care is being taken to build a sense of ownership over the process and achievements so as to bolster the flood early warning system (FEWS) in Bangladesh.

18.3.6 Reporting and Quality Control

Reports were prepared to fulfill the information needs of the different stakeholders to whom the program is accountable. It was therefore important in the M&E process to ensure that the reports were of a high quality. In this regard, factors such as data consistency and evidence were of prime concern. These were assessed periodically by a dedicated team and by the donors. This helped in improving the overall system of data collection and validation. And all along, gender was made a mandatory part of the reporting process

18.3.7 Reviews, Reflections, and Learnings

Different mechanisms such as program advisory committee meetings, biannual reviews, and monthly staff meetings provided opportunities for collective understanding, reviews, reflections, and learnings. In all of this, monitoring and evaluation played a big part, and evidence seeking was accorded high priority. It was also important to ensure maximum participation at these gatherings, both of women and men. The meetings were also avenues for individuals to reflect upon their work and conclude whether it had made any difference to the entire program.

18.3.8 Revisiting ToC and Adjusting Plans

One of the important steps in the MEL framework is to help managers and decision makers adjust their plans and adapt to any emerging situation. Comparing what is happening with what was expected and planned for helps determine how a program can adjust its plans and responses (Douthwaite et al. 2018). In this regard, biannual reviews and planning workshops and learning synthesis were duly conducted. These reviews shed light on what was working and what was not and created a better understanding about the emerging situation, thereby helping populate the original ToC with greater detail and paving the way for necessary amendments, whether minor or major (Douthwaite et al. 2018). The ToC for this project was first developed in 2014 was later revised in 2016 in order to bring about a stronger focus on user engagement and to sustain the impact of EO services (see Chap. 2 for more details). As things stand, the plans are usually adjusted biannually if the need arises.

18.4 Results and Discussions

The implementation of the framework based on ToC and PIPA has produced some results; some of them are briefly described below.

18.4.1 The Ability of the Implementing Staff to Change Direction

Since its inception in 2010, SERVIR-HKH has carried out decadal mapping of land cover to record changes and to support monitoring system in the region. In 2015, the Development Alternatives Incorporated (DAI) evaluated this system. Its report says that the country partners were reluctant to use this system, and the accuracy of the products was their major concern.

But the situation has changed by 2020. The scientists, together with the country stakeholders, have developed a ToC for the system. This has helped the stakeholders and the experts to not only develop clarity on the objectives, but has also provided them the opportunity to tailor the system to the needs and priorities of the users. The system has now been upgraded with capability to generate annual land cover map. The Forest Research and Training Center (FRTC) of Nepal which is the key partner and user has now pre launched the Nepal land cover monitoring system (NLCMS) and has allocated fund for the field-based validation process. This shows a sense of full ownership and a buy-in of the system. Now Bangladesh's Department of Forest is planning to adopt this at the national scale after it successfully launched a pilot. ICIMOD is providing support for the system in both the countries.

This example demonstrates the fact that the EO data scientists and the stakeholders are now giving more importance to adoption and use rather than merely to the application. With this shift in focus, the scientists have proactively started to engage the users in the process of formal and informal service development. As a result and because of the increased trust, the service is now more tailored to the needs of the users. The individuals concerned have also deepened the evidence-based reflection process, whereby they evaluate as to whether their work choices have made any changes as explained by the ToC.

The implementation of this ToC and PIPA approach in planning, monitoring, and evaluation has made the managers and decision makers to change the direction of their work toward one that makes impact. ToC and PIPA continuously focus on the outcome right from the design stage. The PIPA process through which the ToC and performance indicators were developed has brought in clarity, and a collective understanding about how EO and GIT applications should be used for addressing complex problems. Once the managers understood the pathways to ensure the adoption and use of EO products and services, their management priority changed to one of appropriately adapting to any emergent situation. The focus is now more on outcomes and impacts rather than inputs and activities.

18.4.2 Staff Buy-in to the Approach

The staff at SERVIR-HKH has also been slowly able to develop an interest in this approach; this came about after they understood the facet and value of accountability, learning, and adaptive management. Several things have helped in instilling this interest. For example, PIPA has provided an opportunity to the stakeholders to have a better grasp on the pathways of change. Besides, they have found that the ToC which was developed at the PIPA workshop has been extremely useful in strengthening their communication network. This has also helped them to systematically plan, monitor, and evaluate the program, so as to achieve the stated objectives. Now, in discussions and management decisions, the ToC has become a permanent feature.

Once the managers and decision makers understood the value of this approach as well as of monitoring and evaluation, there has been a key change in the management culture. At the individual level, the people concerned are reflecting on their own actions, so as to engage in a process of continuous learning and adaptation to change (Schon 1983). The staff and the stakeholders have now started to ask critical questions of each other at meetings and discussions, and all of these are based on the program's ToC. This has also ushered in a culture of learning and sharing. At staff meetings, M&E is a prime agenda, and the focus is on regular reflections on actions to achieve the best possible results. As there is now a systematic approach to result tracking and measurement, evidence seeking and trust have become an intrinsic part of the work culture. These reflections have also made individuals break away from the traditional patterns of thinking and acting (Klerkx et al. 2012).

Thus, there has been a palpable change in the management approach of the scientists, whereby they place the welfare of the stakeholders at the forefront. And, they are reflecting on their work to see if their work choices have brought any changes, so as to make right choices from best possible way.

18.4.3 Partners Able to Bring Multiple Perspectives

The earlier flood early warning system (FEWS) of Bangladesh, with a four-day lead time, had been unable to reduce the loss and damage from floods. So, the country's flood forecasting and warning center (FFWC) decided to increase the lead time with support from ICIMOD. While the discussions focused on the impact pathways to change, the stakeholders realized that merely increasing the lead time of the warning would not be as effective if it was not combined with information on the flood-risk level and its impact on the ground. Therefore, FEWS was strengthened by increasing the lead time to 15 days, and a provision was also set up to provide information on the potential impact of the flood. Further, there was the realization that the field staff played an important role and that there should be community access to such information.

This case demonstrates that the data scientists and the stakeholders were able to think differently by bringing in multidimensional perspectives on service design. There was also an increased focus on outcomes, impacts, reviews, and reflections, all guided by ToC and PIPA. This is a continuous process facilitated by PIPA that allows different stakeholders to come up with diverse ideas, so as to tailor a project according to the practical context on the ground. Moreover, this flexible process helps in adapting to any emerging situation and paves way for out-of-the-box solutions. Open dialog among all the stakeholders also helps them to analyze and reflect on their actions to determine what is working and what is not (Earth Village 2020). This improves the mechanism of informed decision making to achieve the intended results.

18.4.4 Stakeholders Able to Develop a Sense of Ownership and Trust

A sense of ownership and trust among stakeholders is important for the adoption and use of EO and GIT services. The implementation of this framework based on ToC and PIPA has helped the stakeholders to feel a better sense of ownership and trust mainly in three ways. The first has to do with the overall PIPA process. It has provided an opportunity for the stakeholders to be engaged right from the beginning of the program, at the design stage itself. This has helped them to have a deeper understanding about the project or service and its relevance to their needs. This made for a good beginning in terms of building trust. The collective process of PIPA has also helped the staff and stakeholders to be properly motivated about implementing their respective projects (Douthwaite et al. 2020). Secondly, being able to co-create and co-develop solutions have also fostered a heightened sense of ownership. The third aspect has to do with improved relations among all the relevant parties. The continual formal and informal process of user engagement has improved the relationship between the data scientists and the country stakeholders which has also helped to increase trust among them. The stakeholders, by being increasingly engaged, feel more responsible toward the products and services, and along the way, interpersonal trust is also built, thereby leading to greater adoption and internalization of technology (Lippert and David 2016).

18.4.5 Breaking the Gender Silence in Data Service

Mainstreaming gender tends to be context-specific as opposed to an "off-the-shelf" process (Kadel et al. 2017). The field of EO–GIT is considered especially challenging in terms of mainstreaming gender. So, the aspect of gender was given prime priority when it came to developing the ToC for SERVIR-HKH. PIPA organized with multidisciplinary team became a good enabler to bring exclusive gender lens at design stage itself. This process initially triggered heated discussions between the data scientists and the social scientists, with the former opposing the idea and the latter supporting it. They had an argument that mainstreaming gender would not always be possible and EO and GIT field could be the one. Finally, they agreed to two key mainstreaming approaches: consider gender while developing the EO products, so as to reduce gender gaps and promote gender balance in participation in project events and in staffing. This step helped managers to develop a gender mainstreaming framework for the entire SERVIR-HKH program (Chap. 15). But while the silence on gender has been broken in the EO and GIT field, much more remains to be done.

18.5 Challenges

18.5.1 Iterative Learning Process

The staff involved in this project are experts in EO and GIT but not trained in approaches such as RBM. In several cases, they had to teach themselves about these approaches. As mentioned earlier, the use of ToC and PIPA are aimed at creating a better understanding about all the complexities involved in a program. This is more about "learning-by-doing" for which the staff and the stakeholders have to possess the requisite patience. However, at the same time, the managers are under pressure to produce results. They cannot keep trying out things for too long. They should be able to make the best choice by keenly observing and monitoring the emerging situation. But all said, it is always a challenge to strike a balance between the learning process and achieving results.

18.5.2 Balancing Simple and Complex Theories

The implementation of the ToC and PIPA approach demands the engagement of diverse groups; so, to keep their interest alive, it is essential to simplify the whole process. But it is also equally important not to ignore the complex part and over-simplify matters. Striking a balance between these two is challenging. The idea is to keep things as simple as possible but not at the cost of losing important information.

In SERVIR-HKH, we have localized the ToC and PIPA approach at the service level to facilitate deeper analysis. A tabular format of the ToC with all the necessary elements has further simplified the process. This tabular format has helped diverse stakeholders to engage in the PIPA process, especially at the early stage of developing the EO service. Once clarity came about, the staff and stakeholders again referred to the ToC diagram with its feedback loops as it nicely summarizes how and why change happens. We have always been for simplifying the ToC diagram as far as possible but without losing important information. This is because such simplification will make it easier for the non-M&E professionals to understand the pathways better and use them frequently for communication, reflection, and learning. But the accompanying narrative is still important, particularly to explain the feedback loops and assumptions that can be subsequently tested (Barnett and Gregorowski 2013). Besides, it is important that M&E professionals work closely with other staff and stakeholders to strengthen this process.

18.5.3 Impact Assessment

EO and GIT aims at supporting evidence-based decision making for addressing the problems that people face. The larger society will benefit only if the decisions are implemented properly; the primary consideration is that these applications and products ought to be widely adopted and used at different levels. It has also got to be accepted that the impact on the beneficiaries or the wider civil society may not be seen until well after the time frame of a particular project or a program (Simister and Smith 2010). Therefore, the purpose of capacity building of the country stakeholders to generate and use EO data and GIT services in most cases is less discussed and loosely defined. Impact assessment in such a situation becomes difficult. There are also many people working in this field who argue that measuring the effect of adoption and use of EO applications and services is beyond the scope of this entire program.

18.6 Lessons Learnt

18.6.1 Transformation Requires Support from Top Management

In our decade-long experience, we have observed a big behavioral change in the SERVIR staff involved in project management. The availability and access to EO data and products were the primary goals in the early days of SERVIR-HKH. Now, the focus has shifted to the adoption and use of EO services for societal benefit.

This change would not have been possible without support from the senior management. Trust and support from the senior management in terms of these approaches have encouraged the staff to embrace the new ways. Learning from both success and failure is important, as is also understanding the complexity of a program and the pathways of change. In this context, incentives need to be in place to regularly collect evidence around a theory, test it periodically, and then reflect and reconsider its relevance and assumptions (Barnett and Gregorowski 2013). This requires consistent commitment and support from the top management. Buy-in from the top (Schuetz et al. 2017) and acceptance by the managers and decision makers enable effective implementation of such approaches and strategies.

18.6.2 Localized Approach Simplifies Operation

While there is a general understanding that a ToC has to be placed at the higher level of a program on the complexity front, the SERVIR-HKH experience shows that equal importance ought to be accorded to a localized approach at the service level. This localized approach helps to contextualize the broader concept and renders the operations more effective. In fact, each EO service is a unique case in terms of issues, partnerships, and opportunities. The PIPA process adopted to develop EO services in SERVIR-HKH has provided the opportunity to understand the context better and align the service with the needs of the stakeholders and the users. And the ToC keeps the common goals intact and helps the stakeholders in nurturing them during the implementation phase.

18.6.3 Building Individuals' "MEL Value Perspective"

Value perspective plays a big role in the RBM and learning process. "MEL value perspective" refers to a different way of looking at and working with MEL values where individual work choices are driven by continuous learning through evidence seeking, monitoring, and evaluation (Hyatt and Ciantis 2014). Our decade-long experience with this program shows that developing an MEL value perspective in scientists is a slow and complex process, but it is important if they are also managers of a complex program or project. Institutionalizing collective planning and learning as a part of M&E requires the capacity building of staff, and they also have to be properly motivated (Douthwaite et al. 2018). The staff may be experts in their subject but they may not have had training in the ToC and PIPA approach and RBM. This was reflected in the early days of the SERVIR-HKH program, wherein the EO applications could only be put to limited use (DAI 2015; Morrison et al. 2017). Ensuring that EO applications benefit people in need is more about management rather than science. The effective management of a complex program for sustainable impact is a continuous learning process. In this regard, a multidisciplinary work culture where different views are valued requires to be promoted for collective understanding and learning.

At SERVIR-HKH, we place more value on the participatory process and continued reflections, in line with the ToC, at both individual and group levels. Breaking away from the earlier practice, M&E has become a regular feature at staff meetings. Besides, practical trainings and refresher workshops have been held, focusing on the individual's M&E roles and responsibilities, thereby enabling them to contribute toward achieving the bigger objective. As a result, the scientists are now more open to different views and learnings in the overall process of delivering EO services. The user has also been placed at the forefront of this process—recognizing that it is the needs and interests of the user that matter the most, and user engagement has been accorded the topmost priority in the SERVIR-HKH program.

18.6.4 Flexibility Matters

The ToC and PIPA approach is used to build better understanding about a complex program or change process. This aspect of complexity may not always be fully understood, at least in the beginning (Barnett and Gregorowski 2013). Therefore, the flexibility of accepting imperfection in the ToC at the beginning is important. It will be improved upon as the understanding develops over time. Flexibility may also be required in the steps and overall process since a diverse set of stakeholders may be involved in a particular program.

18.7 Conclusion

In the context of SERVIR-HKH, the ToC and PIPA used in planning, monitoring, and evaluation has helped managers and decision makers to push the boundary beyond EO applications and toward creating meaningful impact. The successful adoption of this approach has helped managers, data scientists, and country stakeholders to change direction; wherein the focus now is on results, developing a sense of ownership, and building trust in the EO applications, this has led to a spurt in the use and adoption of these applications. The PIPA approach has allowed the stakeholders and users to come together in order to arrive at a common understanding about how EO and GIT applications would help in addressing the problems of the HKH region. And the ToC produced through PIPA has provided a good basis for program implementation, monitoring, and evaluation. The participatory approach used in the implementation of the program has not only helped in harnessing the complexity of the program, but has also tailored the services to suit the needs of the users; the inclusion of the aspect of gender is a good example here.

Nevertheless, several challenges are yet to be overcome. It is important here to emphasize upon the iterative nature of the learning process; so, the staff and stakeholders need to be patient all through the whole process. In this, support from the top management also has a vital role to play. Another challenge is in simplifying the whole process while there are several complex elements to it. It has also got to be borne in mind that programs like SERVIR-HKH follows a long pathway by its nature to create impact. But in the first place, the impact part has to be clearly defined, so as to avoid ambiguity about the bigger picture and to accurately measure the impact.

The focus of SERVIR-HKH has been on adopting a localized approach to operationalize the bigger picture, so that there is complete understanding about the context in which the program is being run. While having a ToC in place is a good beginning, it is as important to make adjustments as the project cycle wheels along and the strategy being adopted matters for the best results.

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Chapter 19
Lessons and Future Perspectives of Earth Observation and GIT in the HKH

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19.1 Introduction

During the last decade, SERVIR has been striving for realizing its vision of "Space to Village" by implementing services that provide innovative solutions to improve livelihoods and foster self-reliance with the help of EO and geospatial technologies (Chap. 1). Over these years, there has been significant development in the field of EO and geospatial technology. However, the capacity of the key agencies to utilize these advancements to produce, disseminate, and use information has not been able to catch up with these developments. As cited in the previous chapters, SERVIR-HKH has been working with various partners and stakeholders in co-developing and implementing applied, user-driven EO and geospatial information services in the HKH region. SERVIR-HKH recognizes that the sustainability of information products and applications and their use requires an understanding of users and their needs. Understanding the user's needs and organizational context is the key to delivering effective services. As illustrated in Chaps. 2 and 3, the needs assessment study revealed that the use of geospatial data in the region started in the early 1990s, but there are still gaps in the institutionalization and sharing of information. Often, individual agencies produce geospatial information for their own purpose and do not share it due to lack of policies. Besides, in most cases, the information would have been generated through specific projects funded by external agencies without proper sustainability planning. And as has happened in many cases, those services could not be continued due to lack of resources and capacity.

SERVIR-HKH has gone through a continuous learning process to improve and innovate the service design and delivery approach. From the experiences of the first phase, it was realized that systematic service planning was required to define the roles of the partners at different stages of service development, delivery, and

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B. Bajracharya et al. (eds.), *Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*,
https://doi.org/10.1007/978-3-030-73569-2_19

maturity. The service planning approach (Chap. 2) adopted by SERVIR facilitates a clear understanding of the implementation pathway of service from conceptualization to sustainable adoption by the partners. Well-designed toolkits to provide guidance at each step of service planning, including needs assessment, design, monitoring, and delivery, supported by a strategy for user engagement, communication, gender, capacity development, and M&E have been the fundamental aspects of successful implementation of the service planning approach. The specific focus on gender and social inclusiveness were important to ensure that the services were beneficial for the marginalized populations. The participatory impact pathway and the theory of change, together with the monitoring and evaluation process, have also been helpful in keeping the process on track to achieve the expected outcome.

Institutional arrangements with partners are critical to their engagement in the development and implementation process. In this regard, the systematic capacity building of the partners to use the applications and interpret the information products is necessary. The support from subject matter experts and the Applied Science Team from US universities and institutes also enabled to build the capacity of the regional hub and develop information solutions to cater to the users' needs. Further, the global SERVIR network led by NASA facilitated the incorporation of the latest methods in data analysis and system development; while the integration of NASA's applied science project with the service design process enabled the hub team to use state-of-the art methodology and build the capacity of the team and the partner agencies.

In this chapter, we look at the key lessons that have been learnt and the future directions of the EO applications through initiatives like SERVIR.

19.2 Lessons from the Thematic Services

As described in earlier sections, SERVIR-HKH prioritized four broad service areas: agriculture and food security; land use, land cover change, and ecosystems; water and hydro-climatic disasters; and weather and climate. The specific services were developed through recommendations after the needs assessment stage. Although a common approach of service planning was used in service design and development, each thematic area in different countries had their specific needs and challenges. In the following sections, we present our experiences in implementing the service in the different service areas.

19.2.1 Agriculture and Food Security

SERVIR-HKH has focused on drought monitoring and crop area mapping as two of its primary services (Chaps. 4 and 5). Early assessment of the cereal crop area and production helps in providing critical information in terms of managing food security. In this context, the availability of EO images from the optical and SAR sensor with high spatial and temporal frequency enables the assessment of crop area and assists in monitoring crop health across a large geographic area, thereby supplying critical insights into potential production loss. Also, the availability of free cloud-based access and processing platforms like GEE opens up more opportunities to develop a standard automatic data-processing system that reduces dependence on highly skilled human resources and computing hardware. The work with the Afghanistan Ministry of Agriculture, Irrigation, and Livestock (MAIL) for developing a wheat-area mapping system is an example of establishing one such system. The collaboration with the Bangladesh Agricultural Research Council for mapping winter rice in the country has also delivered promising results.

While the automation of the data-processing system reduces the requirement of highly skilled geospatial professionals in the respective agencies, there is still a need for some field data collection for training and validation of the image classification results. SERVIR-HKH has developed mobile applications to standardize the field data collection process. With a short training, such a system could successfully be used for collecting field data. For example, we have trained the staff of the field agencies of Nepal's Ministry of Agriculture and Livestock Development (MoALD) virtually (due to the COVID-19 pandemic), and they have gone on to conduct such fieldwork. This online arrangement made it possible to carry out the activities effectively and on time, even when the movement was limited due to the pandemic.

Meanwhile, the RS-based crop area mapping has been done with more than 80% accuracy. This accuracy could be improved through the estimation of statistical uncertainty and bias adjustment using ground samples. The combination of RS-based mapping and bias correction models could provide the most accurate estimate of the crop area. While an RS-based crop area map provides a good indication as to whether there has been any potential deviation from the average yield, there is still a need for a quantitative forecast of the actual yield. The assessment of the crop area does provide a good understanding of crop production, but a more in-depth understanding of the potential yield is important for better management of food security. In this regard, the satellite-based NDVI monitoring of crop growth is a good tool to analyze the deviations in greenness at different growth stages. This information is adding more insights into assessing the condition of crops and gives prior signals about any yield loss.

Traditionally, crop yield is estimated using the crop-cut survey in which systematic samples are collected from the crop fields. Yield estimation could be done either empirically using statistical or machine learning model or using process based models. The crop area from remote sensing together with historical yield data could be used for the development of empirical yield model. The crop area and the input from the drought monitoring model could be integrated to develop process-based yield model. Monitoring drought-related stress on crops at different stages of their growth can also help in managing irrigation and thereby reduce the risk of production loss.

While a seasonal drought warning system can provide important information that can be used for agriculture planning, the uncertainties involved in such a prediction and the lack of understanding about those uncertainties by the farmers limit the use of such a system. Thus, capacity building of the agriculture extension workers and farmers in the interpretation and effective use of the drought forecasting system is vital for the broader uptake of drought predictions.

19.2.2 Land Use, Land Cover Change, and Ecosystem

Land cover mapping is one of the oldest applications of remote sensing. Over the last decades, the HKH countries implemented many land cover mapping projects with funding and technical support from different international agencies. Depending on the funding sources and the available images and expertise, these projects used different data sources and methodologies for land cover mapping. But these land cover maps, due to their differences in resolution, classification schema, and class definition, are not suitable for change analysis which is required for various reporting purposes. The methodology used for land cover map generation was also rather tedious and producing land cover maps for multiple years was time consuming and costly. With the progress in cloud-based access to time series satellite images and processing platforms, land cover maps can be generated relatively easily for all the countries within HKH. For example, the archive of Landsat images with GEE was instrumental in developing the Regional Land Cover Monitoring System (RLCMS) algorithm and tools (Chap. 6) to produce annual land cover maps for the years 2000–2018 for the entire HKH region. Meanwhile, SERVIR-HKH has also helped develop country-level systems for Afghanistan, Bangladesh, Myanmar, and Nepal in partnership with the corresponding national departments.

While RLCMS has provided an approach and process for consistent time series land cover data, there have been some limitations and challenges beyond the control of the system development team. While the land cover maps for earlier years suffers from lack of quality reference data, the maps produced via the new method do not match with the legacy data or the published statistics; so, government agencies are hesitant to adopt the new data. While developing land cover maps, it is important that all the potential users of the data sets understand and agree with the definition of different land cover classes. However, despite all the efforts to develop a classification schema with the unambiguous class definition, there are some classes where the users do not agree on the definition.

The lack of adequate human resources and frequent transfer of officials have been some of the key challenges in the sustainable use of the new mapping method. While the process of co-development of the national land cover maps for Afghanistan and Nepal has built the capacity of the partner agencies, it is important to have regular feedback and the mechanism of backstopping to sustain the production of future land cover maps. Also, the Landsat-based maps are not adequate for more detailed classification of some land covers classes; this can be improved by using higher-resolution images like Sentinel II or through the fusion of images from multiple sensors. Besides, the improvements in the machine learning algorithms can be used for enhancing the accuracy of the existing classes or the inclusion of new ones.

While RLCMS provides information on the forest cover extent and the change dynamics that are useful for monitoring deforestation, in the HKH region, forests are also going through degradation, resulting in a thinning of canopy density, loss of biodiversity, and increase in the occurrence of invasive plants (this is particularly critical in the case of Nepal). Degradation happens due to both anthropogenic and natural processes. To address this issue, SERVIR-HKH has developed a climate resilient forest management system (CRFMS) to analyze how climate change can lead to forest degradation (Chap. 7). This information can be used for sustainable forest management by integrating it in the planning and management of forest ecosystems. Apart from analyzing the impact of climate change on the natural processes, CRFMS considers the various aspects of forest use and users.

One of the primary contributors to forest degradation in the region has been forest fires (Chap. 8). The fire-risk maps for Nepal developed by SERVIR-HKH has been useful for the development of a management plan based on the risk level of different districts. However, there are several limitations to the MODIS-based fire-monitoring mechanism due to its coarse resolution. Also, as in the case of Nepal, satellite-based observations do not really provide information on the damage caused by forest fires since most of these are understory fires. To capture and assess the fires and the damages they have caused, it is necessary to deploy a feedback system that collects information from the field. As for the larger HKH region, while the monitoring system has been useful in keeping an eye on fire incidence, a fire-risk forecasting system would be more effective in better planning of resources. In this regard, the capacity of the respective government agencies to operate the system is critical.

Our experiences show that partnerships and iterative engagements with user agencies from the very beginning are critical to ensuring the effective use of the monitoring system. In this context, the forest user groups should also give due weightage to the gender aspect in forest conservation. While the system was developed within the forest management context of Nepal, the efforts to outscale it in Myanmar have shown that the system can be useful across the region. However, this will require understanding different management contexts and identifying common issues through stakeholder consultations and participation. This will then pave for resilient forest management in the region and beyond.

19.2.3 Water and Hydro-climatic Disasters

Floods create havoc every year in the region during the monsoon season. There have been numerous efforts made by the national agencies and humanitarian organizations to improve upon the prior warning system for floods that can help save lives and properties. SERVIR-HKH has made efforts to enhance the flood early warning system in the region through its streamflow forecasting system (Chap. 9). The streamflow forecasting system has been highly effective in reducing the gap in flood forecasting in the region. For example, this regional system has provided discharge information for rivers without gauges which gave a better idea about transboundary flows in the case of Bangladesh. This system, based on a 15-day ECMWF (European Center for Medium-Range Weather Forecasts) projection, has produced very good results in capturing riverine flood. However, it has failed to capture events such as localized flash floods in the smaller catchments of the mid-hills. To address this issue, another forecast system, integrated with the High Impact Weather Assessment Tool (HIWAT) weather prediction model, has been developed, and this has shown the potential to capture such events (Chap. 12). For this purpose, systematic validation of the system with in situ data is crucial, but this has been a challenge since most of the small rivers do not have field stations. Another issue is access to such data which is limited due to the data policy and processing schedule of the respective agencies. Support from the Department of Hydrology and Meteorology (DHM) in Nepal and the Flood Forecasting and Warning Center (FFWC) in Bangladesh in the validation of the systems has been very useful. The experiences in the region show that coordination with the national agencies is crucial for the implementation of these systems; thus, it is important to build the confidence and capacity levels of the national agencies so that the system is used effectively.

Another information that is sought during flood events is on the extent of the flooded area; this information is required to support relief and response measures. The efforts of SERVIR-HKH in near-real-time mapping of inundation using SAR images (Chap. 10) have been effective in responding during flood events, especially in a context wherein cloud cover is a major limitation in the case of optical EO applications. These inundation maps are also highly accurate. Some of the challenges in terms of SAR have been about the availability of these images, the temporal frequency of data, and the time delay between the satellite acquisition of images and the availability of them for analysis. The SAR-based analysis also enables information on the water extent during a flood season; however, it cannot differentiate the floodwaters from the existing waterbodies and this hinders the mapping of the actual flood extent.

Another challenge is that while the system of streamflow prediction captures the rise and fall of water level within a stream, it is unable to provide any information on the damages to people and properties. Thus, the ultimate need is for a system that predicts flood extent and depth and also integrates population and socioeconomic data in it, thereby aiding in the assessment of damages and in the setting up of better response planning.

Under the thematic area of water and hydro-climatic disasters, another application undertaken by SERVIR-HKH has been the mapping of glaciers and glacial lakes of Afghanistan for the years 1990, 2000, 2010, and 2015 (Chap. 11). Being an arid and semiarid country, irrigation in Afghanistan is highly dependent on water from glacier melt. Thus, the assessment of glacier meltwater becomes important, also in terms of planning for hydropower. The impacts of climate change on the glacial environment have been one of the major concerns in the HKH region, especially Afghanistan. Thus, information on glacier area and volume, and changes over time are crucial for water resources and food security of Afghanistan. To address this gap SERVIR-HKH collaborated with the National Water Affairs Regulation Authority (NWARA) of Afghanistan to develop a glacier database for the country.

While the collaboration has led to the acquisition of glacier data for 1990–2015, at a five-year-intervals, the database needs to be duly updated and maintained with more recent data. More frequent annual data would also provide an option for analyzing glacier changes, along with other climatic variables. One of the technical challenges in the development of an updated glacier database is about identifying glaciers in areas with shadow, cloud, seasonal snow, or debris. This requires manual correction through visual interpretation, which is a labor-intensive process. One of the immediate applications of the time series glacial lake data is to identify the potentially dangerous glacier lakes in the country and to prioritize the riskiest glacial lakes depending on the physical and socioeconomic parameters for its continuous monitoring. A GLOF risk reduction strategy can also be established to reduce the risk and increase the resilience of the vulnerable communities. A policy to strengthen national and institutional capacities in order to implement GLOF-resilient development pathways will be very important for the country.

19.2.4 Weather and Climate

A reliable system to provide location-based forecast of extreme weather events like thunderstorm, hailstorm, and lightning has been needed in the region for a long time. The ensemble-based probabilistic forecast by HIWAT has been effective in filling some of the gaps in weather prediction in the HKH region (Chap. 12). The probability matched means from this ensemble forecast of precipitation also provides a more reliable prediction of high-intensity precipitation that might cause a flash flood in the mountainous river catchments. But while the forecast generated through HIWAT has shown a high degree of accuracy in predicting extreme weather, there is a lot of scope for improving the model and the configurations. As things stand, the data dissemination system now provides better access to forecast for meteorologists in the national agencies. But the current visualization system needs to be made easily understandable to the decision makers.

Currently, the system is implemented in NASA's SOCRATES, an HPC system set up for supporting the regional hubs. SERVIR-HKH's strategy for sustainability of this system has been to deploy it at the national agencies. However, the resources required for HPC is a significant bottleneck in this regard, even though the Bangladesh Meteorological Department (BMD) has made good progress in installing this system. Although SERVIR-HKH has organized several training events for the professionals from national agencies to use the system, more specialized training are required for the independent operation and maintenance of the system.

19.3 Lessons from Crosscutting Areas

SERVIR-HKH services are constantly guided by the intent to fill the major gaps and needs in the field of EO and geospatial applications in the region. The services have been developed to come up with the desired information products that can support decision-making at various levels. In this context, a number of crosscutting components play a crucial role in creating an enabling environment that can ensure the successful implementation of the services. These components are well identified in the service planning toolkit, and our experiences in these areas are presented below.

19.3.1 Geoinformation Technology

The approach of SERVIR-HKH toward selecting GIT solutions has been based on the institutional capacity of the partner agencies, and it has focused on the capacity enhancement of these agencies, thereby resulting in better adoption of the geoinformation system (Chap. 13). The glacier monitoring system in Afghanistan, streamflow forecasting in Bangladesh, and the National Land Cover Monitoring System in Nepal are some of the successful examples. SERVIR-HKH has also tried to improve the accessibility to these services by the rural communities who are constrained by poor internet connectivity and bandwidth limits. While the cloud-based processing system for a large volume of satellite data was a breakthrough in the development of land cover mapping and flood information services in the region, the existing capacity—in terms of IT infrastructure and technical skills—of the partner agencies in adopting these systems is still a major challenge. Besides, the rapid evolution of GIT and the need for maintenance and frequent updating of hardware and software have become critical constraints for the sustainability of these services.

19.3.2 Capacity Building

The capacity gap in the region was identified as one of the challenges for the successful implementation and use of geoinformation services. These challenges related to: selecting the right people from the partner organizations; keeping up to date with fast emerging and changing technologies; reducing the gender gap in participation; and ensuring the use of the learnings in actual operations. The multi-tier capacity development program of SERVIR-HKH, focusing on individuals and institutions, has produced very good results (Chap. 14). The combination of topic-based trainings in technologies and on-the-job trainings in system development and its use has been found to be useful in the successful co-development and deployment of the services in the partner agencies. Specialized trainings were conducted for the faculty of universities have been highly appreciated as they have also helped in developing a curriculum for geospatial science. Another highlight of the SERVIR-HKH training module to promote geospatial technologies has been its focus on women.

Our overall experience tells us that capacity building must be made a strong component of SERVIR-HKH service development and delivery. Our learning has also been that a more innovative approach needs to be adopted for reaching out to wider communities. The capacity building of the end user of the services is also vital to ensure the effective use of the systems. Besides, customized trainings and orientation programs for the higher management and policymakers are important for better adoption of these systems within the government agencies. In this regard, a number of events were also organized virtually during the COVID-19 phase, and this has given us new insights into online training approaches. While there were some limitations due to lack of face-to-face interactions, these virtual trainings successfully organised; also, they were cost-effective in terms of logistics and could accommodate a larger number of participants.

19.3.3 Gender Inclusion

Like other science and technology fields, there exists a considerable gender gap in the field of EO and GIT in the HKH region. There are far fewer women professionals in this field compared to men. There is a great need for improving women's access to geoinformation and their role in decision-making. For this, the services and products require customization for generating gender-inclusive information and building the capacity of women to use these products.

Gender inclusiveness is part of the SERVIR-HKH framework (Chap. 15). Our efforts to increase women's participation in capacity building through explicit women-focused events were successful in reaching out to more women. These events generated awareness as well as gave young women an opportunity to learn about the prospects of the GIT field. While some of the services could integrate gender and social issues, a lot more needs to be done in this area. A big issue in including more women professionals in the co-development process was that there is a lack of such professionals in the partner agencies. Targeted capacity building activities have to be carried out in this regard through universities and other relevant platforms. It is obvious that more gender-integrated studies as well as information products tailored for women and other marginalized groups would be helpful in extending the reach of these information services.

19.3.4 Communication

Strategic communication (Chap. 16) is important for successful service design, delivery, and adoption. At the beginning of a service design process, communication is mainly internal and focused on ensuring that all the partners and stakeholders have the same knowledge and understanding of the products and services. At this stage, the communication activities aim to prepare materials on the product and services targeting the co-development partners to elaborate on the purpose and features of the services. At the later stages of the service delivery process, the communication activity focuses on the development of outreach materials targeting the end users. For effective communication, translation of some of the materials and interfaces in multiple languages are sometimes required. As communication is a continuous process, the materials need to be updated as per the progress of service development and delivery. While scientific articles or technical documentations are required for building the confidence of partners and the scientific community, descriptive materials are equally necessary for the wider users to build awareness about the services. The narration of success stories also helps to demonstrate the use and impact of the services. Besides developing communication materials, conducting regular communication campaigns is also crucial. These can be by way of technical and dissemination workshops, forums, newsletters, and social media campaigns. Constant engagement with media outlets is also an important facet of effective communication.

19.3.5 User Engagement

Systematic engagement with partners and stakeholders is an integral part of the service design and delivery process. The user engagement process within SERVIR-HKH has evolved over time and a dedicated user engagement mechanism was included in the service design and implementation from the beginning of the second phase (Chap. 17). The concept of co-design and co-development was adopted as a key strategy. Our experiences have been that the users are not homogeneous in terms of their situation, need, and capacity. For effective engagement, the collaboration strategy should be tailored to the situation of individual users. Continuous engagement with the key partners is also important and formal partnership agreements like MoU (Memorandum of Understanding) and LoI (Letter of Intent) are helpful in facilitating the process. Also, the involvement of various other stakeholders should not be overlooked. And it goes without saying that co-design and co-development are essential for the long-term sustenance of these services.

19.3.6 Monitoring and Evaluation

Creating sustainable impacts in society through informed decision-making is the ultimate goal of SERVIR-HKH. The theory of change (ToC) approach adopted by SERVIR has been instrumental in aligning the service delivery process with outcomes and impacts on the ground (Chap. 18). The PIPA process has helped in building collective understanding between the SERVIR team and the partners for analyzing and developing the ToC for the services. This was important in terms of clarifying expectations and co-designing and implementing the services. This has also helped in the collective monitoring of progress and achievement. The PIPA process introduced at the service planning stage in the second phase has led to an improvement in aligning the service design and delivery components with user needs. However, PIPA, ToC, and MEL involve iterative processes and flexibility to adapt to the changing needs. For example, revisiting the ToC as per the project timeline helps partners to re-evaluate the products and services and thereby make the necessary adjustments. Moreover, defining clear indicators to track the changes in terms of outcomes and impacts, based on regular data collection and analysis, is important to ensure that the efforts are going in the right direction.

19.4 Future Directions in EO Applications and Opportunities

The opportunities for applications of EO in the HKH region are highly influenced by the global trends and the priorities set by the nations that are leading the space race. In addition to NASA as the leader in space exploration, the new strategy of the USA in deep space exploration has clearly identified the potential roles of the different government departments and the private sector (White House 2020). The achievements of SpaceX (www.spacex.com), a private company, in the development and reuse of orbital-class launch vehicles, thereby reducing substantial costs in the space industry, can be expected to bring a paradigm shift in the design and launching of EO satellites in the coming decades. Among the many planned missions of NASA, Landsat 9 is expected to provide continuity to the current monitoring applications, and NASA-ISRO Synthetic Aperture Radar (NI-SAR) will provide opportunities for many new applications on disasters, water resources, and vegetation monitoring (www.nasa.gov). Similarly, the Copernicus Space Component of the European Union has plans for expanding the Sentinel system to incorporate six high-priority missions: Anthropogenic CO2 Monitoring (CO2M); Land Surface Temperature Monitoring (LSTM); Polar Ice and Snow Topography Altimeter (CRISTAL): Copernicus Imaging Microwave Radiometer (CIMR); Copernicus Hyperspectral Imaging Mission for the Environment (CHIME); and the Radar Observing System for Europe in L-band (ROSE-L) (FutureEarth 2020). With the policy of Copernicus being to provide free access to Sentinel data, the EO community is highly optimistic about new and enhanced services in the areas of atmospheric, oceanic, cryospheric, and land global monitoring. There are also numerous space missions planned by Japan, Korea, China, India, and many other countries. Besides, the initiatives of the Committee on Earth Observation Satellites (CEOS) on international coordination of civil space-based EO programs in the development of compatible data products, formats, services, applications, and policies, and to optimize societal benefits, have been commendable in building collaborations and synergies. These efforts are also being supplemented by the Group on Earth Observation (GEO) with its many regional initiatives like AOGEO and thematic initiatives such as GeoGLOWS, GEOGLAM, GEOBON, and GEO Mountains, which are relevant to addressing the many concerns of the HKH region. The GEO has a dedicated initiative on EO for sustainable development (EO4SDG) to support the UN 2030 Agenda, in order to organize and help realize the potential of EO and enable societal benefits through the achievement of the SDGs (Anderson et al. 2017). In the context of all the HKH countries striving to achieve the SDGs, such initiatives provide frameworks and guidance on the applications of EO for various indicators.

Besides these trends in the field of EO, many disruptive technologies are progressing rapidly that will change the way we utilize EO data and information in the near future. To list a few of them, the Internet of things (IoT) will support billions of connected devices to sense the essential elements of our Earth environment and develop innovative paradigms for distributed computing. AI is another rapidly evolving technology that is increasingly being applied in the analysis of large volumes of EO data to extract meaningful information accurately and efficiently. The integrated use of AI, powerful cloud-based computing infrastructure, and new 5G connectivity with sensor networks in IoT is expected to bring in unprecedented opportunities at both local and global levels (Genderen et al. 2020).

In the context of the HKH, we see many opportunities due to a huge gap in data, capacities, and services in EO and GIT, and also because of the increasing acceptance of these technologies by the national agencies as a means to improve the decision-making process. The signing of a declaration by the eight governments of the region supporting ICIMOD's HKH Call to Action during the "Hindu Kush Himalaya Ministerial Mountain Summit 2020" on 15 October 2020 shows a growing commitment to strengthening regional cooperation, promoting a united voice for the HKH at regional and global levels, and enhancing the uptake of scientific evidence for improving policies in the region on mountain environments and livelihoods (ICIMOD 2020a). Out of the six immediate actions identified by the call, Action 6 calls for promoting regional data and information sharing and science and knowledge cooperation in order to fill the data gaps and develop actionable knowledge that is mountain focused and HKH specific (ICIMOD 2020b). The efforts being made by SERVIR-HKH will directly contribute to addressing this call. SERVIR has also come up with its "SERVIR Strategic Plan 2020–2025" which states that one of its three strategic goals is to enhance its leadership power and influence globally. This reflects that the knowledge and experience generated by the SERVIR-HKH hub, in collaboration with its partners, have firmly established it as the regional center of excellence in the application of EO information. There is now growing confidence among the partners about SERVIR-HKH's applications and services. Indeed, the SERVIR network, with its many institutions worldwide and its regional hubs across the globe, provides a unique opportunity for cross-hub learning and working on innovative solutions using the current and future developments in EO and geospatial technologies.

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