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The sustainability of our planet is currently a major concern for the global community and has been a central theme for a number of major global initiatives in recent years. Perceiving a dire need for concrete benchmarks toward sustainable development, the United Nations and world leaders formulated the targets that make up the seventeen goals. The SDGs call for action by all countries to promote prosperity while protecting Earth and its life support systems. This series on the Sustainable Development Goals aims to provide a comprehensive platform for scientific, teaching and research communities working on various global issues in the field of geography, earth sciences, environmental science, social sciences, engineering, policy, planning, and human geosciences in order to contribute knowledge towards achieving the current 17 Sustainable Development Goals.

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Contributions are welcome from scientists, policy makers and researchers working in fields related to any of the SDGs. If you are interested in contributing to the series, please contact the Publisher: Zachary Romano [Zachary.Romano@springer.com].

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# Spatial Information Technology for Sustainable Development Goals

Springer

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*The new agenda is a promise by leaders to all people everywhere. It is a universal, integrated and transformative vision for a better world. It is an agenda for people, to end poverty in all its forms. An agenda for the planet, our common home. An agenda for shared prosperity, peace and partnership. It conveys the urgency of climate action. It is rooted in gender equality and respect for the rights of all. Above all, it pledges to leave no one behind.*

—UN Secretary-General BAN Ki-moon

# Preface

The future of the planet and of life on Earth is explored in Rachel Carson's book *Silent Spring*, published in 1962, which begins with a 'fable for tomorrow', presenting the true story of the use of DDT that had caused damage to wildlife, birds, crops, agricultural livestock, domestic pets and even human beings. In 1968, Garrett Hardin published a paper titled 'The Tragedy of the Commons' which summarised the population problem, unrestricted use of resources and environmental pollution. The international NGO The Club of Rome, founded in 1967, has dedicated itself to the study of the 'world problematique'. The term describes political, social, cultural, environmental and technological problems from a global, multidisciplinary and long-term perspective. It attracts scientists, researchers, business people and heads of state from around the globe. In 1972, researchers from the Massachusetts Institute of Technology (MIT) presented a model, 'Limits to Growth', published under the auspices of The Club of Rome, which explained the ecological limits to economic and demographic growth. It was the result of mathematical simulations conducted on predictions of demographic and economic growth correlated with the exploitation of natural resources and forecasted up to 2100. They investigated five major trends of global concern, such as accelerating global industrialisation; rapid world-population growth; widespread malnutrition caused by poverty; dependence on non-renewable resources and their accelerated depletion; and the deteriorating environment. The MIT researchers concluded with three major points:

1. If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on Earth are satisfied and each person has an equal opportunity to realise his or her individual human potential.
3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.

The conclusions of ‘Limits to Growth’ were controversial, but the report contains a message of hope that ‘Man can create a society in which he can live indefinitely on Earth if he imposes limits on himself and his production of material goods to achieve a state of global equilibrium with population and production in carefully selected balance.’ This was the first movement toward a definition of the foundations of a development mode that we qualify today as sustainable.

In 1972, The United Nations Conference on the Human Environment took place in Stockholm, Sweden, which for the first time explored ecological issues of global concern. The conference concluded with a declaration of principles and an action plan to fight pollution. In 1984, the United Nations Assembly gave Gro Harlem Brundtland the mandate to form and head up the World Commission on Environment and Development. The commission’s mandate was to recommend means to the international community to preserve the environment through improved cooperation between developing and developed nations, while considering existing relationships between peoples, resources, the environment and development. In 1987, the work of the World Commission on Environment and Development produced a report entitled ‘Our Common Future’, also known as the Brundtland Report. She wrote in the foreword to the Report:

> ‘A global agenda for change’—this was what the World Commission on Environment and Development was asked to formulate. It was an urgent call by the General Assembly of the United Nations:
>
> - to propose long-term environmental strategies for achieving sustainable development by the year 2000 and beyond;
> - to recommend ways concern for the environment may be translated into greater cooperation among developing countries and between countries at different stages of economic and social development and that lead to the achievement of common and mutually supportive objectives that take account of the interrelationships between people, resources, environment and development;
> - to consider ways and means by which the international community can deal more effectively with environment concerns and
> - to help in defining shared perceptions of long-term environmental issues and the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community.

In 1972, the UN Conference on the Human Environment brought the industrialised and developing nations together to delineate the ‘rights’ of human society for ensuring a healthy and productive environment. A string of such meetings followed regarding the rights of people to adequate food, housing and access to safe water.

The present decade has been marked by a revival of social concerns. Scientists are drawing our attention towards urgent and complex problems bearing on human survival: a warming globe, threats to the Earth’s ozone layer and the desertification of agricultural land. We respond to these problems inappropriately at the local level and by assigning the problems to institutions ill-equipped to cope with them. Environmental degradation was first seen as mainly a problem of the rich nations and a side effect of industrial wealth, but currently it has become a survival issue for developing nations. It is part of the downward spiral of linked ecological and economic decline in which many of the poorest nations are trapped. Despite official hopes expressed on all sides, no trends are identifiable today and no programmes or policies offer any real hope of bridging the growing gap between rich and poor nations.

In 1992, The Earth Summit, held at Rio de Janeiro, Brazil, also popularly known as the United Nations Conference for Environment and Development (UNCED), gave rise to the Rio Declaration on Environment and Development and articulated an action plan called Agenda 21 for sustainable development. The World Summit on Sustainable Development, also known as Rio+10, held in 2002 in Johannesburg, South Africa, focused on the renewal of global commitment which was defined in the Rio Declaration and Agenda 21. The World Summit also included among its targets the elimination of poverty; changes to consumption patterns and non-viable production; and the protection and management of natural resources. The Johannesburg Declaration focused on:

> the indivisibility of human dignity which is resolved, through decisions on targets, timetables and partnerships, to speedily increase access to such basic requirements as clean water, sanitation, adequate shelter, energy, health care, food security and the protection of biodiversity. We will work together to help one another gain access to financial resources, benefit from the opening of markets, ensure capacity-building, use modern technology to bring about development and make sure that there is technology transfer, human resource development, education and training to banish underdevelopment forever... give priority attention to the fight against the worldwide conditions that pose severe threats to the sustainable development of our people, which include: chronic hunger; malnutrition; foreign occupation; armed conflict; illicit drug problems; organised crime; corruption; natural disasters; illicit arms trafficking; trafficking in persons; terrorism; intolerance and incitement to racial, ethnic, religious and other hatreds; xenophobia; and endemic, communicable and chronic diseases, in particular HIV/AIDS, malaria and tuberculosis... (18–19)

On 8 September 2000, the United Nations General Assembly adopted the United Nations Millennium Declaration. Among other aspects of the Declaration, the General Assembly adopted the eight Millennium Development Goals (MDGs), most of which were anticipated to be achieved by 2015, such as the eradication of extreme hunger and poverty; universal primary education; gender equality and the empowerment of women; reduction of child mortality; improvement to maternal health; combatting HIV/AIDS, malaria and other diseases; ensuring environmental sustainability; and developing a global partnership for development. In 2012, Rio+20, the United Nations Conference on Sustainable Development (UNCSD) held at Rio de Janeiro, Brazil, marked the twentieth anniversary of the Rio conference. The main objective for Rio+20 was to secure a renewed political commitment for sustainable development along with assessing progress and bridging the gaps in the implementation of sustainable development efforts; and addressing new and emerging challenges.

Ambitious action plans for people, prosperity and the planet were accepted in 2015 to achieve the agenda for sustainable development by 2030. There are 17 sustainable development goals (SDGs), including eradicating poverty, strengthening universal peace through collective partnership, and promoting eco-growth, social inclusivity and environmental sustainability.

Spatial information technology is not only providing information on the Earth's resources but it is also useful for managing them in an integrated, inclusive and sustainable manner in order to achieve SDGs. The present book is an effort to develop knowledge about spatial information technology for contributing towards the UN's SDGs among students, researchers, professionals and laypeople. This book is organised in order to facilitate understanding of spatial databases and how to extract information from them for planning purposes. It describes the basic fundamental concepts concerning advanced techniques for spatial data management and analysis. It also discusses the methodology to proceed practically in a systematic manner. The text then presents the basic concepts underlying geographic information systems (GIS), remote sensing and global positioning systems (GPS) for resource and infrastructure planning and their management with the aim of developing these skills among students and young researchers. Geo-scientists can also enhance their knowledge through the use of this technology. The chapters of this book are systematically arranged in such a way that readers can easily understand the conceptual background and do their hands-on practice with GIS software.

Part I discusses the fundamental concepts in eight chapters and Part II deals with their application as case studies from different disciplines. Chapter 1 discusses the requirements of spatial information technology by incorporating descriptions of what is meant by remote sensing, GPS and GIS as well as linkages between them, the fundamental technological requirements, components and types of GIS. Chapter 2 explains the database structure considered to be the backbone of a GIS environment. Various types of spatial and non-spatial databases are explained in it. Chapter 3 presents the fundamental concept of remote-sensing technology as one of the major sources of spatial databases. Chapter 4 describes GPS technology used to acquire locational information about the Earth's surface, which is very useful for fieldwork and ground verification. Chapter 5 deals with the basic concept of a geo-referencing system which is a necessary process to provide a real coordinate system for spatial databases and discusses the projection system. Chapter 6 deals with workflow for development of spatial databases needed to finalise the map. The main purposes of the previous chapters are to prepare the final map for resource management, which is discussed in Chap. 7. It describes different methods of spatial database analysis. Finally, Chap. 8 discusses the map visualisation process and different forms of GIS output with the use of geospatial technology. Part II discusses the applied aspects by presenting five case studies (Chaps. 9–13) representing different challenging areas such as the land-use model for agricultural sustainability, flood-inundation mapping, watershed characterisation and prioritisation, infrastructure assessment and crop modelling in order to contribute towards SDGs.

Chapter 14 discusses the application of spatial information technology in other SDGs with suitable examples. Concluding remarks are given in Chapter 15 where global initiatives and the national perspective are discussed.

We are very grateful to various government and non-government departments, organisations and agencies from India and abroad, including the Indian Space Research Organisation, National Remote Sensing Centre, Survey of India, Office of the Registrar General and Census Commissioner, India, US Geological Survey, European Space Agency, and many others for providing databases and information during the writing of this book. We would also like to thank all the authors of the numerous books and various websites we have cited here and from which we obtained valuable material. These are duly acknowledged.

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# Contents

# Introduction

Spatial information technology is a transformative tool universally available to empower individuals to advocate and innovate for our common future. The technology includes remote sensing, global positioning systems (GPS) and geographic information systems (GPS). These technologies enhance our ability to assess and monitor complete socio-bio-physical characteristics of the Earth such as geomorphology, climatology, oceanography, natural resources, disasters, settlement, agriculture, economy and many more to manage and preserve its ecosystems. Thus, this technology has huge potential to help us realize the following sustainable development goals (SDGs) by 2030:

1. No Poverty: End poverty in all its forms everywhere
2. Zero Hunger: End hunger, achieve food security, improved nutrition and promote sustainable agriculture
3. Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages
4. Quality Education: Ensure inclusive and equitable quality education for all and promote lifelong learning
5. Gender Equality: Achieve gender equality and empower all women and girls
6. Clean Water and Sanitation: Ensure access to water and sanitation for all
7. Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable and modern energy for all
8. Decent Work and Economic Growth: Promote inclusive and sustainable economic growth, employment and decent work for all
9. Industry, Innovation and Infrastructure: Build resilient infrastructures, promote sustainable industrialisation and foster innovation
10. Reduced Inequalities: Reduce inequality within and among countries
11. Sustainable Cities and Communities: Make cities inclusive, safe, resilient and sustainable
12. Responsible Consumption and Production: Ensure sustainable consumption and production patterns
13. Climate Action: Take urgent action to combat climate change and its impacts
14. Life Below Water: Conserve and sustainably use the oceans, seas and marine resources
15. Life on Land: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss

16. Peace, Justice and Strong Institutions: Promote just, peaceful and inclusive societies
17. Partnerships for the Goals: Revitalise the global partnership for sustainable development

The present book aims to improve scientific understanding regarding spatial information technology to help communicate the United Nations' SDGs to faculty members, students, researchers, professionals and laypeople. The book describes the basic fundamental concepts and techniques of spatial data management and analysis together with methodological advancement. GIS, remote sensing and GPS are presented in an integrated manner for the planning of resources and infrastructure.

Chapter 1 introduces background information about spatial information system requirements in the day-to-day life of human beings that can address questions such as what, where and when. It also describes the locations, conditions, trends, patterns, modelling of natural resources and occurrences of phenomena. Basically, GIS integrates the components of computer hardware, software, databases, procedures and trained people in order to capture, compile, store, update, manipulate, analyse and display geographically referenced spatial data together with non-spatial information. The development of computer technology has enhanced the concept of map-making (cartography) in the GIS environment as well as increased the capability of decision-making by using huge databases for multidisciplinary applications. The major applications of GIS include mapping, monitoring, measurement and modelling of databases of varied forms. Chapter 2 presents the concept of databases in GIS that play a major role in spatial information technology. Basically, two types of database are used: spatial and non-spatial. These databases consist of the Earth's features converted into the different layers, along with their non-spatial data. These thematic layers may be rendered as raster or vector data models. The vector data store the information as pairs of $x$–$y$ coordinates while raster data are represented in cells. The non-spatial database is stored in alpha-numeric tabular form. Types of non-spatial database include network, hierarchical and relational and these interact with spatial databases by means of a common key such as a unique identification number. The various sources are available in the form of spatial and non-spatial databases such as analogue maps, remote-sensing imagery (both digital and photographic), GPS data, field surveys, census data and primary as well as secondary tabular data.

Chapter 3 specifically deals with remote sensing, a technique to acquire data remotely that employs a multidisciplinary approach to the handling of imagery. There are several mechanisms involved, ranging from the source of energy to the supply of end-product to the user. Remote sensing can be accomplished through three platforms: groundborne, airborne and spaceborne. The product of remote sensing may be in the form of photographs or digital imagery. Electromagnetic energy is the medium by which different sensors acquire information about the Earth's surface. The limited portion of the electromagnetic energy available for remote sensing is known as an atmospheric window. In the atmospheric window, energy interacts with the Earth's features and is reflected back to the upper atmosphere where a deployed sensor records that energy to form an image. The interaction of energy with Earth material such as soil, vegetation and water depends on the nature, properties and configuration of features. The interacted electromagnetic energy is reflected back to the atmosphere where sensors receive it and transmit it to the ground station. The reflectance behaviour of the feature is assessed from the reflectance curve displayed in a computer monitor. There are various Earth-resource observation remote-sensing satellites in orbit, starting with Landsat, one of the pioneers in satellite observation, followed by European and Indian satellites, launched to acquire information about the Earth's surface. The imagery received from the satellite is not directly usable by the user community, thus digital image processing is applied to provide geometric and radiometric correction as well as enhancement techniques to increase the interpretability of the imagery in digital classification and visual interpretation with the help of a photo or image interpretation key. The checking of the classified or interpreted satellite imagery finally needs assessment for accuracy and when completed these classified images can be used as thematic maps. Satellite imagery, once classified, can also be used as input in a GIS environment to create a database as a base layer. Thus, remote sensing provides the base information as well as thematic information to integrate with a GIS environment. The field verification and fieldwork need an accurate information system like GPS, an instrument that provides the precise location of a particular point. Generally, GPS refers to the services provided by the US NAVSTAR (Navigation Satellite Timing and Ranging) satellite network, but GLONASS (Global Navigation Satellite System) and IRNSS (Indian Regional Navigation Satellite System) are also providing positional information from Russian and Indian satellite constellations, respectively. There are space, ground and user segments in GPS. Ground segments control the spaceborne satellites to monitor their operations. The GPS receiver acts as a user which is installed in a road–rail–air–water navigation system. With the help of four satellite signals, a receiver determines the 3-dimensional position on Earth. To enhance the positional accuracy, a differential global positioning system (DGPS) can be used, where a minimum of two GPSs are required, one acting as a base station and another as rover. GPS is widely applied for navigational purposes.

Without a coordinate system, the purpose of spatial data is not fulfilled. In geo-referencing of the spatial database it is therefore most important to understand the location of a particular feature and phenomenon on the Earth's surface. Given its huge size, the Earth is modelled as a globe, with its true shape, distances and directions reproduced at the appropriate scale. The Earth's coordinates comprise a reference system which is used for mapping 3-dimensional aspects on a 2-dimensional plane. GIS software uses two types of coordinate system—a geographic and another planar system that uses data to locate the precise position, since the shape of the Earth is spheroid due to flattening at the poles. There are two types of data used while mapping: one is geocentric and the other local. There are various projection systems, available from the families of cylindrical, conical and azimuthal projection, to represent various locations on the Earth's surface. In India, polyconic, Lambert Conformal Conic (LCC) and Universal Transverse Mercator (UTM) projections are widely used to represent small-scale to large-scale maps. The proper planning of the project is the most important aspect of creating the digital database in a GIS environment. There are various input sources to convert analogue data into digital data, such as scanning of maps, digital remotely-sensed data, digital data from secondary sources and GPS data. The conversion of digital raster data into vector data is done through an onscreen digitisation process. During vectorisation, various errors occur and these are corrected by identifying dangles, nodes, sliver polygons and duplicate features. Sometimes, the errors occur while joining two adjacent maps which need an edge-matching process. The updating of a map can also be corrected by using editing tools available in the software. Topology is the most important feature of GIS, as it illustrates the relationships of connectivity, contiguity and containment between features for spatial analysis purposes. The non-spatial data can also be created in a GIS environment by using GIS software and other software such as Microsoft Excel and dBase. It is attached to spatial data through the common field in both spatial and non-spatial data in the GIS software. The database can also be used to create another data set by a data linkage process in the same coordinate system. It can be classified into two parts, one exactly matching and another non-exactly matching. In exact matching, it is known when the spatial feature is matched and both the data set and attributes are appended in a new data set. Non-exact matching, also classified as hierarchical and fuzzy matching, involves merging the data sets to create a new one in a hierarchy, appending different data sets not matching each other. After creating a digital database it can be used for cartographic mapping and spatial analysis.

Spatial analysis is the most important feature of the GIS software that enhances the decision-making process. It has a wide application in understanding the environment around us and when planning the allocation of resources. Various functions and methods of spatial analysis in different GIS software packages are available and depend critically upon the ability of the GIS engineer to utilise and develop them in a GIS environment. Basically, spatial analysis can be single- or multi-layer, with queries ranging from simple to complex. It is very useful for the quantitative measurements of point, line and polygon to understand the dimensions of features. It also includes the transformation process from single layer to multiple layers such as when creating a buffer zone around the point, line and polygon features as well as when analysing two layers with different features such as *line in polygon* and *polygon in polygon* overlay analysis. The spatial interpolation technique is also utilised to identify an unknown value from known characteristics of the spatial data; methods include Thiessen's polygon interpolation method, the triangular integrated network (TIN) and the digital elevation model (DEM). The spatial data can also be manipulated through the aggregation and merging of data sets to form a new data set. These spatial analysis methods are very useful for the geographical analysis of the data set. The output of the various spatial analyses can also be used for mapping and act as input for other purposes. The overall conceptual road map of conversion of real-world features into digital or analogue mapping is known as visualisation. Map visualisation includes all the steps for decision-making regarding global resources and phenomena. It includes all activities, ranging from thinking about the problems and hypothesis generation to final analysis of results and their presentation by exploring, analysing, and synthesising the facts. The desired output can be represented by cartographic and non-cartographic methods of representation. In this way, spatial information technology is helpful in map-making and decision-making processes.

This book also includes case studies focusing on land-use modelling, morphometric analysis, flood-inundation mapping, infrastructure mapping, crop modelling and applications relating to other SDGs. Spatial information technology employs land-use modelling and suggests various alternate scenarios in such a way that no land should be kept as wasteland; this will help bring about prosperity and environmental enhancement. Another application that includes the calculation of morphometric parameters proves that spatial information technology is an efficient tool in drainage delineation and analysing characteristics for morphometric analysis. The morphometric parameters of different aspects like linear, areal and relief show the different characteristics of the watershed. These characteristics can be used to interpret the geological conditions responsible for the hydrology of the drainage basin. The ten morphometric parameters—drainage density, stream frequency, texture ratio, bifurcation ratio, watershed shape factor, overland flow, circularity ratio, elongation ratio, form factor and compactness ratio—are used for prioritisation of the watershed in high, medium and low categories. The land and water resource development plan should be applied on the basis of priority of the watershed. The applications of spatial information technology are very helpful in the management of flood-inundated areas. The remote-sensing-based analysis reveals that floods in the study area occur in low-lying zones alongside the rivers from September to November, which affect the *kharif* (monsoon season) crops and sometimes also the *rabi* (dry season) crops. The overlay analysis in the GIS provides the statistical assessment of flood-inundated areas in the watershed. In the rural and urban environments, infrastructure is the crucial parameter to assess development. The case study of infrastructure development shows the capability of information technology to identify gaps in the provision of infrastructural facilities such as education, health care, drinking water, transport, communication technologies (i.e. postal service, telephone) and, electrification that are not uniformly available. Spatial information technology can also be applied in crop management and its modelling by incorporating other software extensions in a GIS environment. The last case study shows that there are possibilities to increase the productivity of the soil by utilising geospatial components such as remote sensing, GIS, GPS and simulation models like InfoCrop and QUEFTS in an integrated manner for planning optimal productivity and exploring resource and input management options. The present study provides inputs for policymakers and other agencies for planning the best use of the available resources in order to improve the socio-economic and environmental conditions of the region as well as developing new policies and strategies for sustainable development.