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Case Study

Mapping flooded areas utilizing Google Earth Engine and open SAR data: a comprehensive approach for disaster response

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Abstract
One of the most destructive and frequent natural disasters in the world, flash floods cause millions of people to be displaced annually in addition to seriously harming livelihoods and infrastructure. It affects many ecological components and applications related to water management, natural resources, agriculture, human health, and economics. Himachal Pradesh saw an unprecedented amount of rainfall in June and July 2023, which resulted in exceptionally strong monsoon conditions from July 7 to July 10. Operating out of the Meteorological Centre in Shimla, the India Meteorological Department reported widespread, unusually heavy rainfall throughout the state during this time. Cloud cover often obstructs optical satellite data during the monsoon season, which has led to the investigation of alternate techniques for mapping floods. the whole satellite image processing process was carried out using Google Earth Engine (GEE). The Kangra District's 5739 km2 area was chosen as the study's area of interest. In these circumstances, traditional methods of mapping and monitoring flood-prone areas frequently fall short because of poor visibility and overcast skies during bad weather. Technology such as Synthetic Aperture Radar (SAR) becomes a ray of hope during these desperate times. When SAR data is combined with Google Earth Engine, it becomes even more user-friendly. Using SAR data and the powerful cloud processing platform Google Earth Engine (GEE), this study suggests a flood mapping technique. When it comes to mapping flood areas, the strength of SAR data and GEE surpasses boundaries and challenges. It is evidence of both technological advancement and human inventiveness. Such tools are more critical than ever as the world deals with the increasing effects of climate change and the rising frequency of extreme weather events.

1 Introduction

One of nature's most devastating natural disasters, floods wreak unimaginable havoc on communities all over the world. As per the 2019, Global Assessment Report about Disaster Risk Reduction states that 76 million people were impacted by floods between 1997 and 2017. One way to characterize floods is as water on dry soil. Flooding can be caused by several factors, including too much precipitation, rapid snowmelt, dam failure, storm surges, insufficient management of water techniques, etc. India ranks 2nd globally regarding the number of persons killed by floods, however comparatively speaking, several other nations have more flood-related fatalities per million population than India. India's economy is dependent on agriculture, and the weather, particularly extreme weather events, has always had an impact on the country's economic progress [1]. In addition to significant losses in agriculture, these catastrophic occurrences cause enormous costs in life and property as well as disruptions in business. Himachal Pradesh continues to be the most severely damaged state in North India among all those impacted by the intense rains that fell in July. The Department

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of Revenue, the Himachal government, stated that the estimated cost of the damage in the state is reportedly over Rs 3738.28 crore in monetary loss.

Numerous noteworthy flash floods have transpired in different Himachal Pradesh regions, leading to considerable destruction and fatalities. Notably, a catastrophic flash flood occurred in the Satluj Valley on the night of July 31 and August 1, 2000, raising the water level to 60 feet above normal and causing widespread damage from Khab to downstream areas. The flood destroyed 20 bridges, damaged 200 km of NH-22, and claimed 135 lives, with an estimated loss of income of Rs. 1466.26 crore. Across the Sainj valley in Kullu, Mandi district, Chhota Bhangal, and Baijnath Sub Division of Kangra district, similar events in July 2001 caused a great deal of devastation of infrastructure, a great deal of deaths, and significant financial losses. Another noteworthy incident happened on June 26, 2005, when a break in Tibet's Parachoo Lake caused a flash flood in the Satluj River, causing major damage estimated to be worth about Rs. 610 crore. The region's ongoing risk of flash floods is further demonstrated by subsequent floods in July 2005 and September 2010, which emphasises the urgent need for Himachal Pradesh to implement efficient flood mitigation and management plans (Source: https://hpsdma.nic.in/).

Flood inundation estimate is a significant component in developing damage relief strategies, assessing damage, estimating and allocating compensation, and choosing suitable land use and management in the flood-affected area during an ongoing flood occurrence [2]. The use of satellite remote sensing in our study is based on the fact that conventional flood mapping methods have inherent limitations. Conventional flood mapping, which depends on hydrological modelling and ground surveys, is not only time-consuming but also unfeasible in real-time situations, particularly in places with challenging terrain and restricted accessibility. This is made worse by the fact that flood events are dynamic and require quick data collection and analysis to respond and manage effectively. Conventional approaches are useful in some situations, but they are not always timely or easily accessible, especially in remote areas like Himachal Pradesh. Microwave remote sensing data products are based on observations from sensors operating in the microwave band of the electromagnetic spectrum, which is generally defined as frequencies between 1 and 300 GHz. Microwave sensors can be active or passive, in contrast to optical sensors, which depend on heat emissions or sunlight reflection.

Products derived from satellite remote sensing information are excellent tools for flood mapping because they provide the flawless benefits of synoptic views and reviews. When monitoring regions affected by flooding during a persistent event, data from optical remote sensing are not particularly useful because cloud cover obstructs data retrieval in visible and near-infrared wavelengths. One benefit of microwave remote sensing data products is their ability to penetrate clouds and provide coverage in all weather conditions [3–7]. Active radar devices operating in the frequency range of microwaves are therefore the best choice for mapping flood inundation. Consequently, the sentinel-1 collection was used in the present study to determine the areas of the district affected by flooding. Flooding can be stated from a radar perspective as the presence of a transient or permanent surface of the water beneath a dense or sparse vegetation cover, whether it be open water, agriculture, or a forest. Flood maps are useful for assessing and managing disasters because they show the dynamics and extent of flooding. The mechanism of radar backscatter, which is mainly pertinent to flood inundation, is an important topic to be addressed at this point [8]. Open water appears extremely dark in the satellite image due to specular scattering, which happens when there is a uniform water surface and the image signal travels off from the satellite sensor. When the water's surface is somewhat rough—caused by wind, heavy rainfall, or short-lived vegetation—the signal is scattered, mainly in the direction opposite to the satellite sensor. This phenomenon is known as rough surface scattering. Though these areas appear dark, they don't appear to be as black as the water's perfectly smooth surface. A more uneven surface will cause a brighter pixel in the image and a stronger signal to be dispersed back to the satellite. Due to double bounce dispersion, which happens when a pair of smooth surfaces make a right angle & divert incoming radiation, the majority of the radiation returns to the sensor. In the image, these regions seem to be very bright. In inundated vegetation, which is vertically connected to the horizontal layer of the water, this type of scattering is commonly observed. That is an attribute of cities. Polarization is another key idea about microwaves. The plane in which the signal's electric field propagates is referred to as its polarization, and it can be either horizontal or vertical [9, 10]. There are four possible combinations of the two transmitted as well as received polarizations for radar signals because they can be transmitted and/or acquired through multiple polarization types regardless of wavelength. These include HH horizontal transmission, horizontal reception, HV horizontal transmission, vertical reception, VH vertical transmission, horizontal reception, and VV vertical transmission. Polarization affects the radar signal's penetration depth. In light of the aforementioned, the primary goal of this study is to illustrate how Sentinel-1 SAR images may be used for mapping flood inundations on Google Earth Engine's cloud-based platform [11–14]. The study's operational methodology is used to calculate the area covered by the flooded area.

2 Materials and methods

2.1 Study area

The Kangra district is located between latitudes 31˚ 21′ and 32˚ 59′ N and longitudes 75˚ 47′ 55″ to 77˚ 45′ E (Fig. 1). It is located on the Himalayan southern escarpment. The Shivaliks, Dhauladhar, and the Himalayas span the entire district from northwest to southeast at varying elevations. Beas is a significant river in this town, which is situated where the Baner and Majhi rivers converge. The elevation fluctuates between 500 and approximately 5000 m above mean sea level (AMSL). 9,154 people were living in Kangra according to the 2001 India census. Males make up half of the population, and females the other half. Kangra experiences dry, humid winters in a subtropical climate (classification: Cwa). The district experiences an annual temperature of 26.85ºC (80.33ºF), which is 0.88% higher than the average for India. Kangra has 30.91 rainy days (8.47% of the time) and 30.1 mm (1.19 inches) of precipitation on average per year.

2.2 Data used

The information from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument operating at 5.405 GHz (C band) is provided by the Sentinel-1 mission. Included in this collection are the S1 GRD (Ground Range Detected) scenes, which were ortho-corrected and calibrated through processing with the Sentinel-1 Toolbox. The study utilizes the Sentinel-1 GRD dataset (Table 1) to determine the areas in the Himachal Pradesh district of Kangra that are flooded during floods. Sentinel-1 dual-polarized (VV and VH) SAR images obtained between June 01, 2023, and June 20, 2023, were used for analysis before the flood event, while images obtained between July 22, 2023, and August 20, 2023, were used

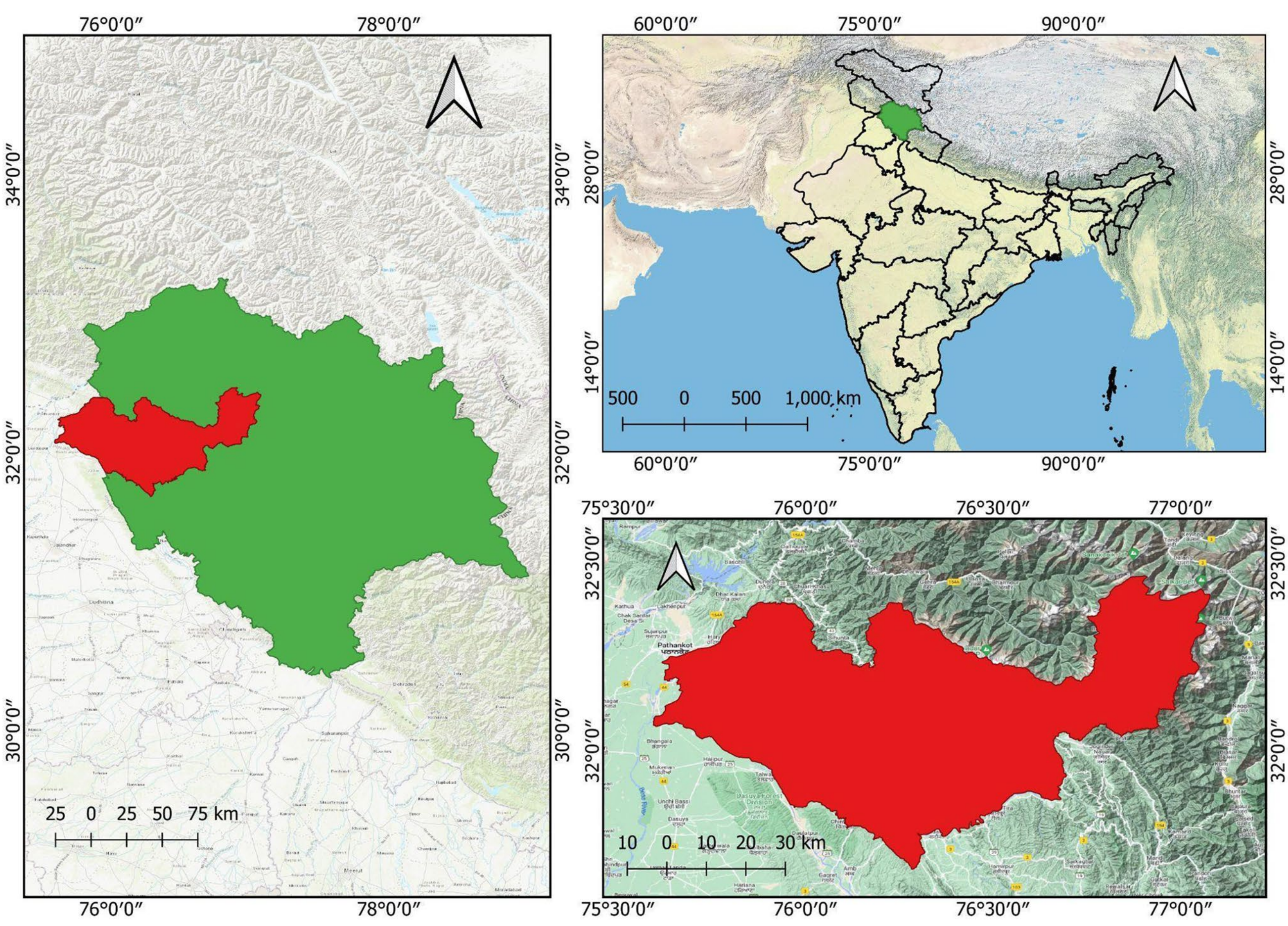


Fig.1 Study area

for analysis after the flood event. VH polarized Level-1 GRD Sentinel-1 SAR images acquired in IW (Interferometric Wide Swath) mode at a resolution of 5 × 20 m (10-m pixel spacing) were used in this study. Furthermore, the state's elevation zones were extracted using the HydroSHEDS product. A mapping product called HydroSHEDS offers hydrographic data in a standardized format for use in regional and global applications. It provides a range of vector and raster georeferenced records at different scales, such as flow accumulations, drainage directions, river networks, and watershed borders. The elevation data used in HydroSHEDS was acquired by NASA's Shuttle Radar Topography Mission (SRTM) in 2000. The resolution of this dataset is three arc seconds. The Drainage (Flow) Direction, Hydrologically Conditioned DEM, and Void-Filled DEM datasets are available at 3 arc-seconds. Sentinel-1 data consists of C-band synthetic aperture radar data. Sentinel-1's whole database is available to GEE. The European Space Agency is providing it with two satellites, Sentinel-1A and 1B, each of which has a 12-day global coverage period. Additionally, data from both satellites is used to obtain global coverage spanning six days over the equator. There are four ways in which the satellite devices gather Sentinel-1 information. These include the following: Strip Mode is available upon request and is intended for specific purposes; Wave Mode is used for regular ocean collection; Extra Wide Swath Mode is used to track oceans as well as coastlines; and Interferometric Wide Swath Mode is utilized for regular land collection (such method is solely utilized for mapping flood).

2.3 Methodology

This study used Google Earth Engine, an online geospatial computing platform commonly used for studying the surface of the Earth, to process the Sentinel-1 SAR data sets. GEE provides a wide range of geospatial datasets and time-series satellite data sets hosted in the cloud at no cost. Additionally, GEE offers a Javascript-based code editor wherein codes for processing, retrieving, and mapping flood inundation of datasets were developed (Fig. 2). The flowchart of the methodology used in this study for mapping flood inundations is shown in Fig. 3. By importing the shapefile of the districts affected by flooding into the GEE code editor platform, the AOI (Area of Interest) was chosen. The preprocessed sentinel-1 data had to be loaded from the GEE's public data archive after the shapefile had been loaded. The image data collection was created and loaded using a variety of filters, including AOI, resolution, transmitter/receiver polarization, instrument mode, and orbit pass. Sentinel-1 data collection preliminary filtering was defined to load the SAR Ground Range data with VH polarization, a descending orbit pass, and Interferometric Wide (IW) instrument mode for the previously set AOI. Another filter was then created to select the data reduced above for specific dates that the flood incident occurred. The aforementioned dataset collection was therefore additionally narrowed by date for both the pre- & post-flood periods. The "from" & "to" dates were set to be June 1 to June 20, 2023, and July 22, 2023, to August 20, 2023, to gather the photos for "before the event" and "after the event", respectively. By mosaicking, the filtered image datasets taken before and after flood events, respectively, a single image in VH polarization mode was created. As seen in Fig. 4a, b, two images were prepared for additional processing. After that, speckle (noise reduction) was removed from both images. A fresh image with regions flooded by the flood was created by dividing the before-flood mosaicked image and the after-flood mosaicked image. A mask was created to make the flooded areas stand out with a difference threshold equal to 1.25. The threshold of 1.25 was selected based on experimental analysis or empirical studies that tested various threshold values to determine which one best distinguished flooded areas from other land cover types with the least amount of false positives (identifying non-flooded areas as flooded) and false negatives (failing to identify actual flooded areas). Finally, by exporting the different images, the area of the flooded area across the AOI was determined.

Table 1 Datasets used

Datasets	Sentinel 1A	
Product	GRD	GRD
Purpose	Pre-flood	Post-Flood
Acquisition Date	01-06-2023 to 20-06-2023	22-07-2023 to 20-08-2023
Beam Mode	IW	IW
Polarisation	VH	VH
Pass	Descending	Descending

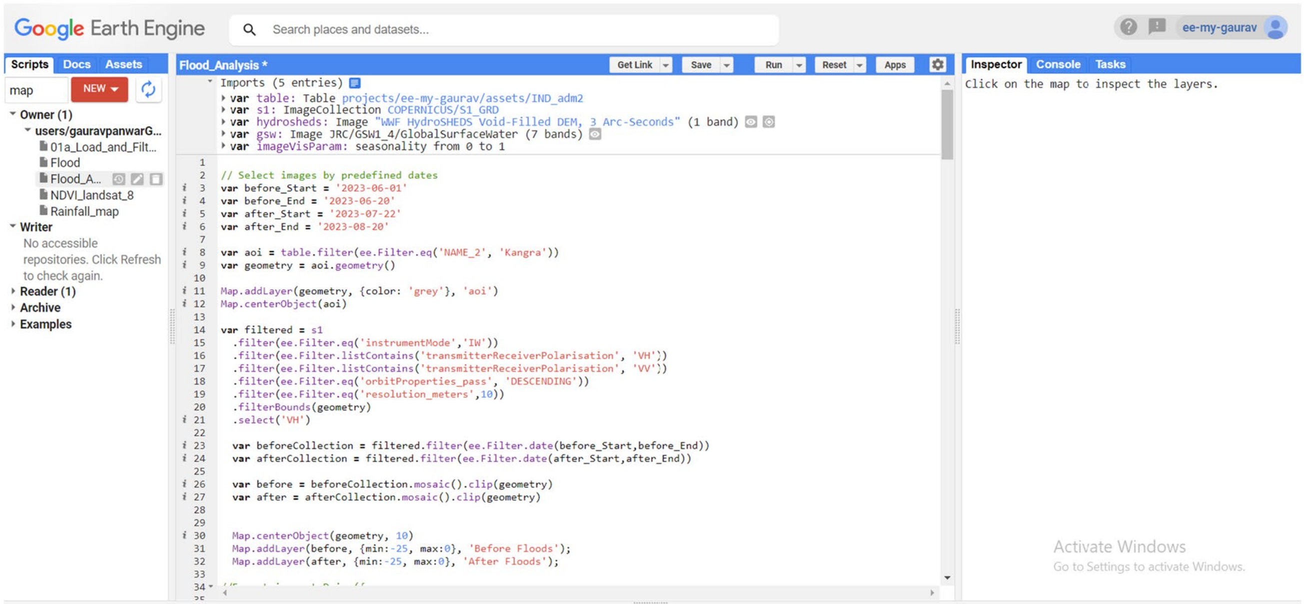


Fig. 2 A screenshot of the GEE JavaScript code editor window

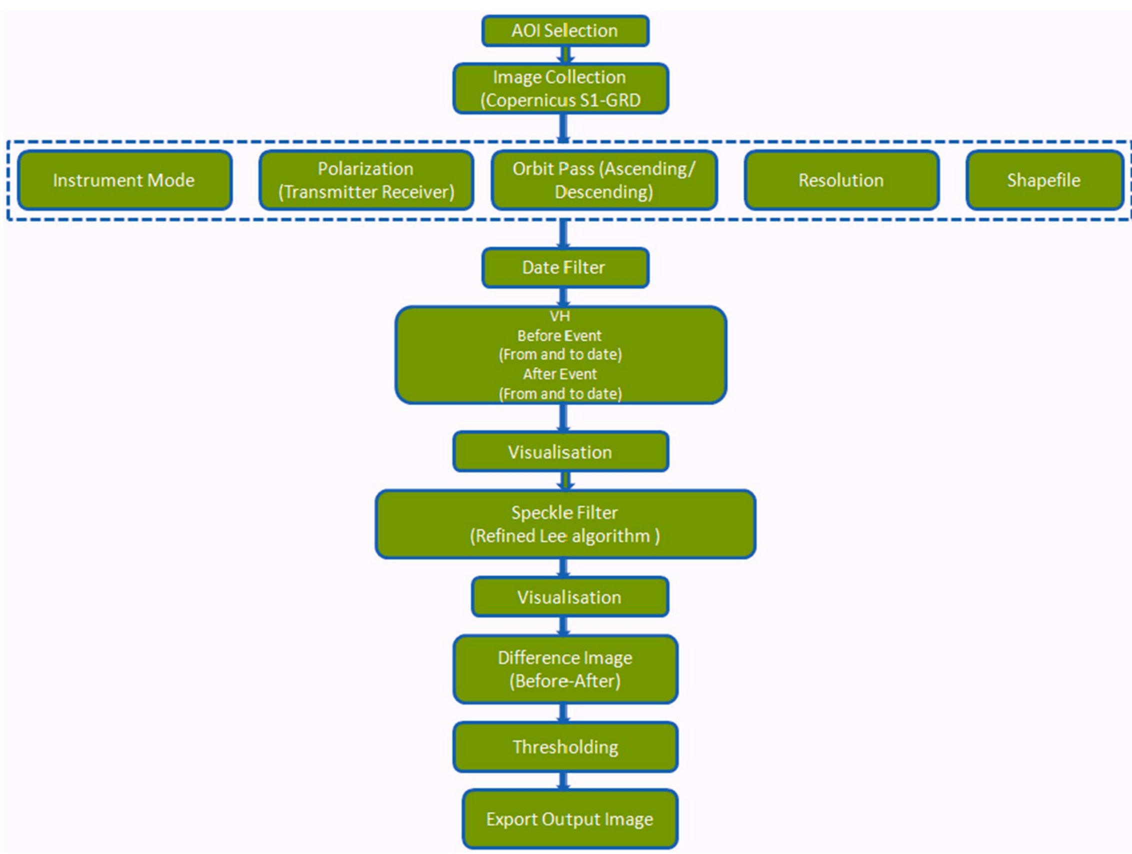
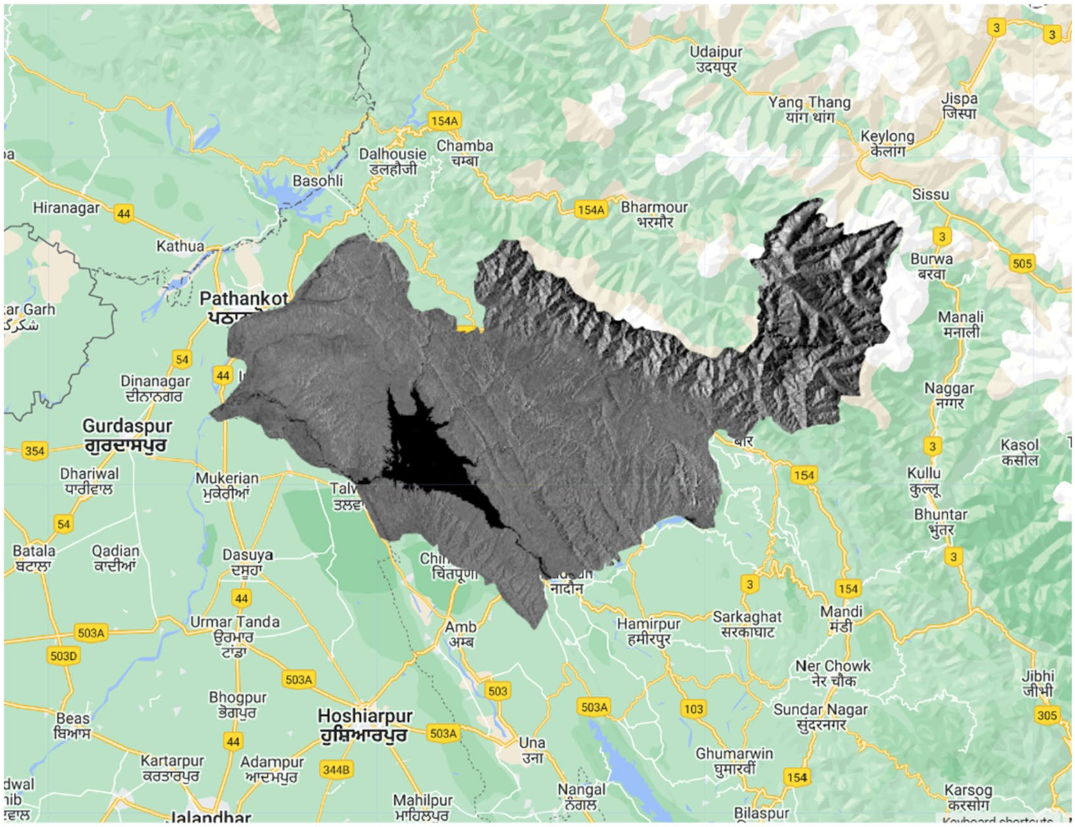
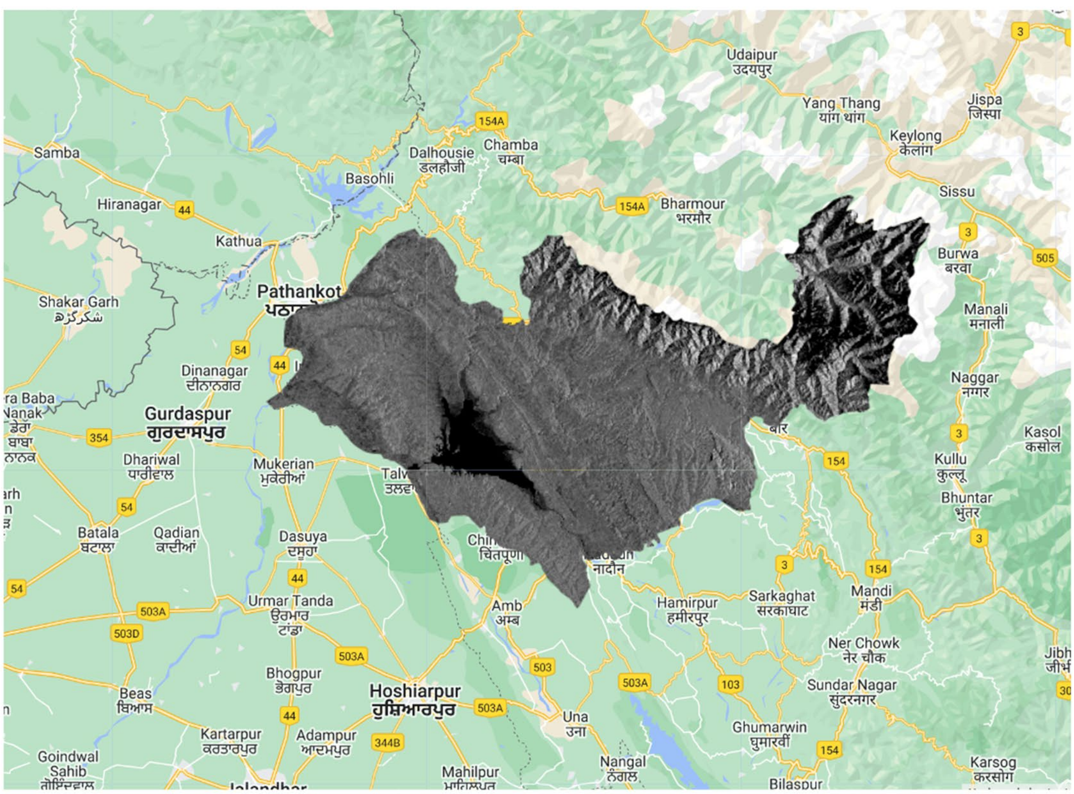


Fig. 3 Steps of image processing

3 Result and discussion



(a) Before the flood event



(b) After the flood event

Fig. 4 **a** Before the flood event. **b** After the flood event

June and July of 2023 saw a high frequency of landslides, floods, and flash floods due to the unceasing rains. Abnormally high floods were caused by a combination of local rainfall and the floodwater from the hills, which occurred at the same time in many plain areas beneath the hills. Over 100 deaths have been reported in Himachal Pradesh, and the estimated damage from landslides and floods is over Rs 3738 crore. The most severely affected state in North India was Himachal Pradesh. (Source: The Economic Times). According to a press release issued on July 12, 2023, by the India Meteorological Department, Meteorological Centre, Shimla (HP), Himachal Pradesh experienced active to vigorous monsoon conditions from July 7 to July 10, 2023, as shown in Fig. 5. During this time, the State saw widespread very heavy to extremely heavy rainfall in most areas. From 1971 to 2020, the state experienced an average of 734.4 mm of rainfall during the monsoon season, which runs from June to September. In just 4 days, from July 7 to July 11, 2023, the state received 223 mm of rainfall out of an average of 734.4 mm. This is an unprecedented deviation of 436% based on historical records. The state's normal rainfall is 41.6 mm. These days saw unprecedented levels of rainfall, which caused extensive damage to both public and private properties as well as the overflowing of major rivers, road blockages, landslides, flash floods, damage to bridges, total disruptions of the electrical and communication systems, and fatalities.

As stated in the methodology, the whole satellite image processing process was carried out using Google Earth Engine (GEE). The Kangra District's 5739 km2 area was chosen as the study's area of interest. In these circumstances, traditional methods of mapping and monitoring flood-prone areas frequently fall short because of poor visibility and overcast skies during bad weather. Technology such as Synthetic Aperture Radar (SAR) becomes a ray of hope during these desperate times. When SAR data is combined with Google Earth Engine, it becomes even more user-friendly. For flood mapping, Sentinel-1 SAR datasets were processed. Speckle noise was eliminated from both the "Before the event" and "After the event" images through processing. Speckle noise, which is frequently the result of electromagnetic wave interference, manifests as erratic, granular patterns in SAR imagery. It may cause the images to lose quality and make them more difficult to understand. We use speckle filtering techniques to get around this, and the Refined Lee algorithm is one of the best ones.

The Frost filter offers a compromise among speckle reduction and detail retention by adjusting the filter coefficients depending on local image variance while working within the presumption of an exponential signal distribution [15]. Although it works well in homogenous areas, it does not perform as well in retaining edge details in heterogeneity places, like flood boundaries.

Similarly, the Kuan filter [16] is a local statistics-based filter that assumes that speckle noise follows a multiplicative model. It is less appropriate for applications needing great spatial accuracy since it tends to smooth out tiny details even in mildly scattered images.

A more adaptive method of handling variable degrees of speckle throughout the image is offered by the Gamma Map filter, which expands upon the Lee filter by adding a Gamma distribution model for speckle [17]. Although it preserves information better than the Frost and Kuan filters, it still performs poorly in regions with a lot of texture.

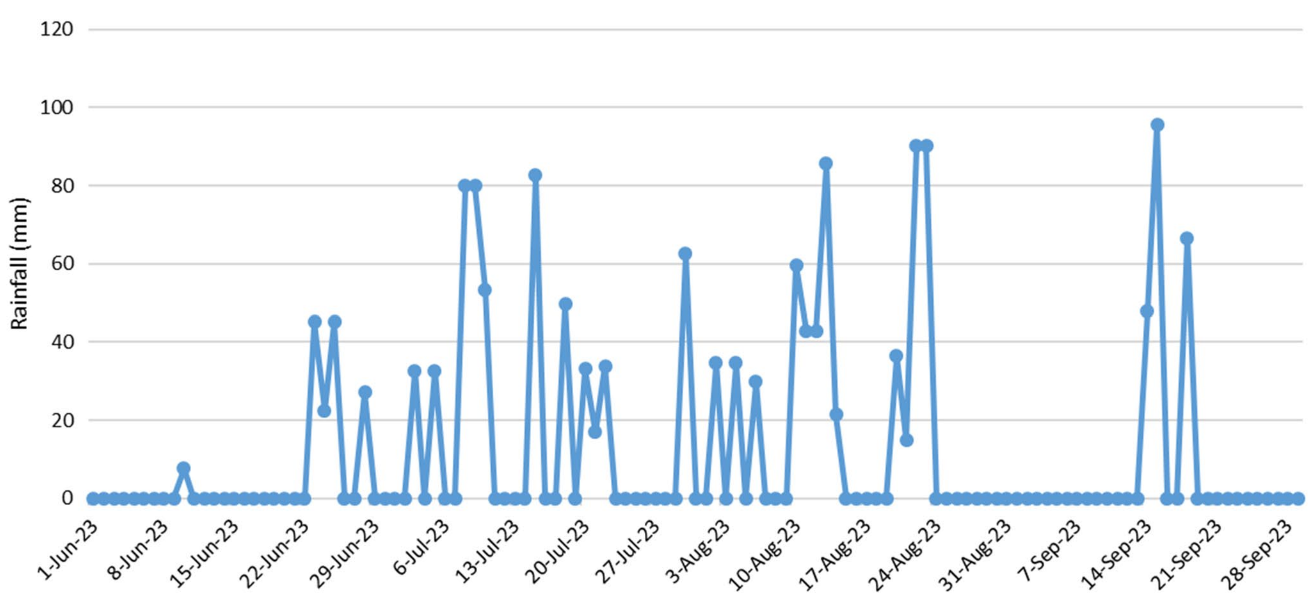
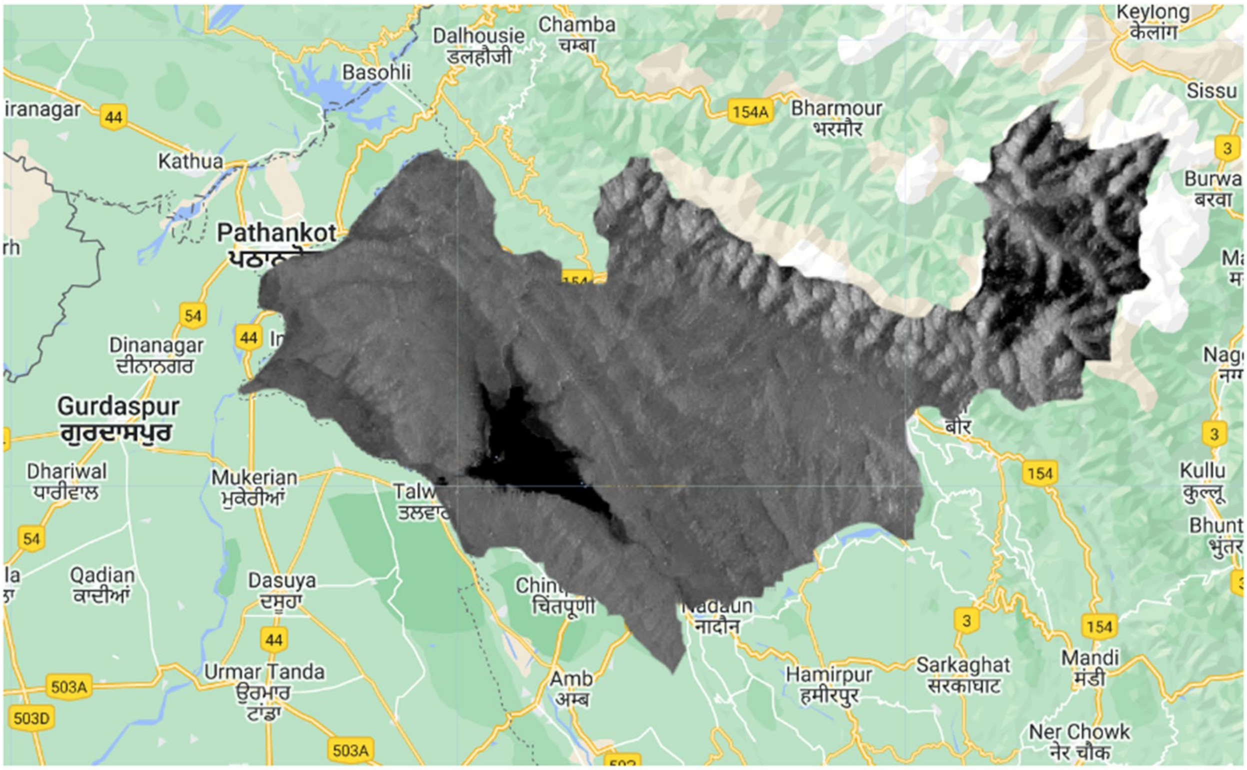
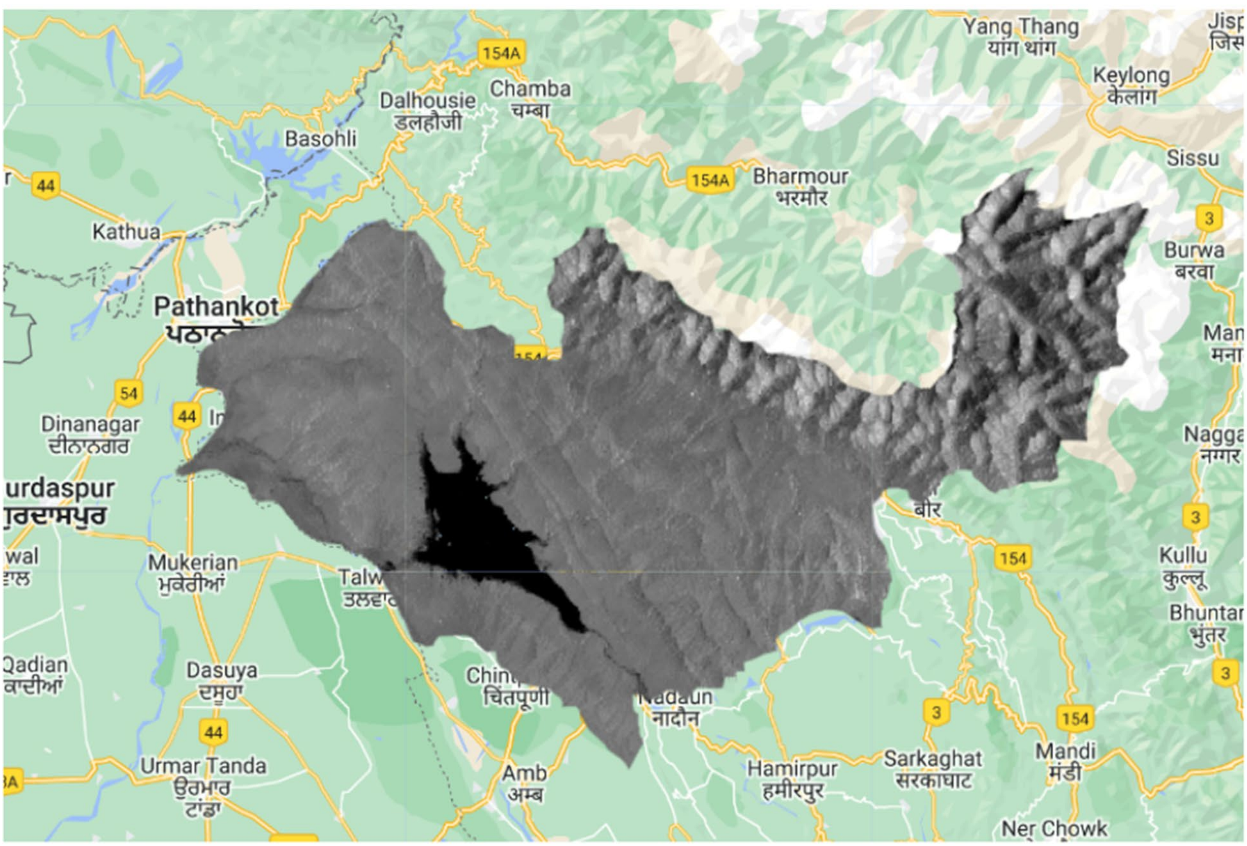


Fig. 5 Rainfall time series graph



(a) Speckle-free Image before the flood event



(b) Speckle-free Image after the flood event

Fig. 6 **a** Speckle-free Image before the flood event. **b** Speckle-free Image after the flood event

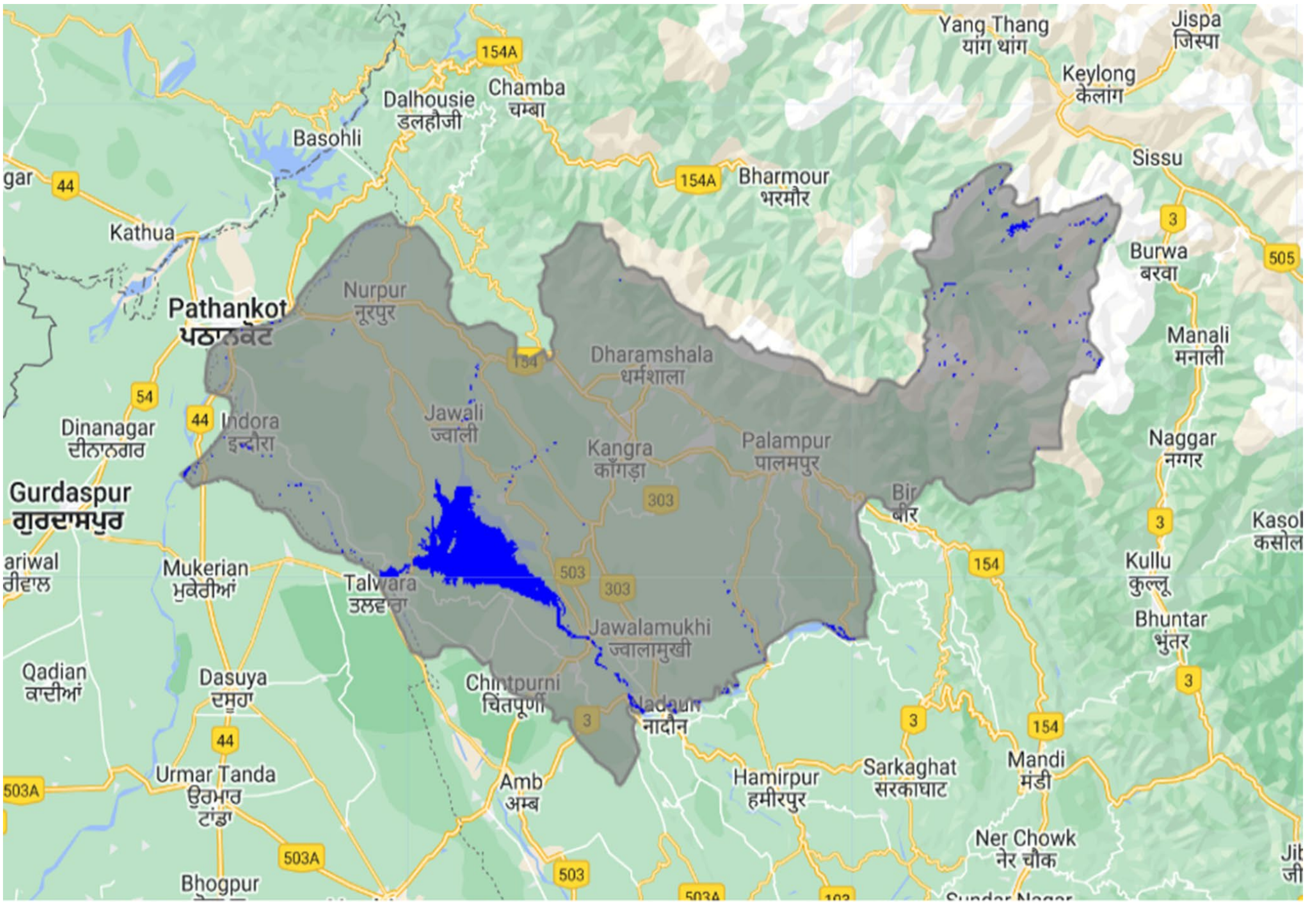


Fig. 7 Permanent Water in Blue Colour

The Refined Lee algorithm is distinguished by its advanced method of speckle suppression, which includes adaptively weighting filter coefficients according to the image's local statistics [18]. This technique is excellent at maintaining structural elements like edges and point targets, which are essential for precise flood delineation, in addition to successfully reducing speckle noise. The algorithm performs better for our study's goals because it can discriminate between relevant image information and noise, especially in regions with high spatial variability.

A strong speckle filter that reduces speckle noise and preserves image features is the Refined Lee algorithm. Its ability to discern between true features and noise makes it especially well-suited for SAR data.

The resulting speckle-free VH polarization images, which are displayed in Fig. 6a, b were then utilized to compute the area that was inundated by comparing the pre-and post-flood values.

Permanent water bodies were mapped using JRC—Global Surface Water to prevent confusion with floodwater as shown in Fig. 7. More precise global-level surface water information can be found in GSW data.

Figure 8 displays the final flood inundation map that was created by interpreting the sentinel-1 SAR images. In the analysis, a roughly 75 km2 area is mapped as flooded, and it is shown in red.

Although this work offers insightful information about mapping flood extent in Himachal Pradesh with SAR data, it also recognises certain inherent limits of the SAR technology and our methodology. First off, there's a chance that SAR data misclassifies flood maps due to limitations in its ability to distinguish between flood waters and other wet surfaces like wetlands or damp soil [19]. Furthermore, Townsend [20] notes that dense vegetation can have a substantial impact on the radar signal, creating uncertainty when interpreting flood extents beneath wooded canopies. By addressing these drawbacks, we hope to shed light on the limitations of our work and the inherent difficulties in using SAR data for flood mapping, opening the door for further research to improve and enhance our methodology.

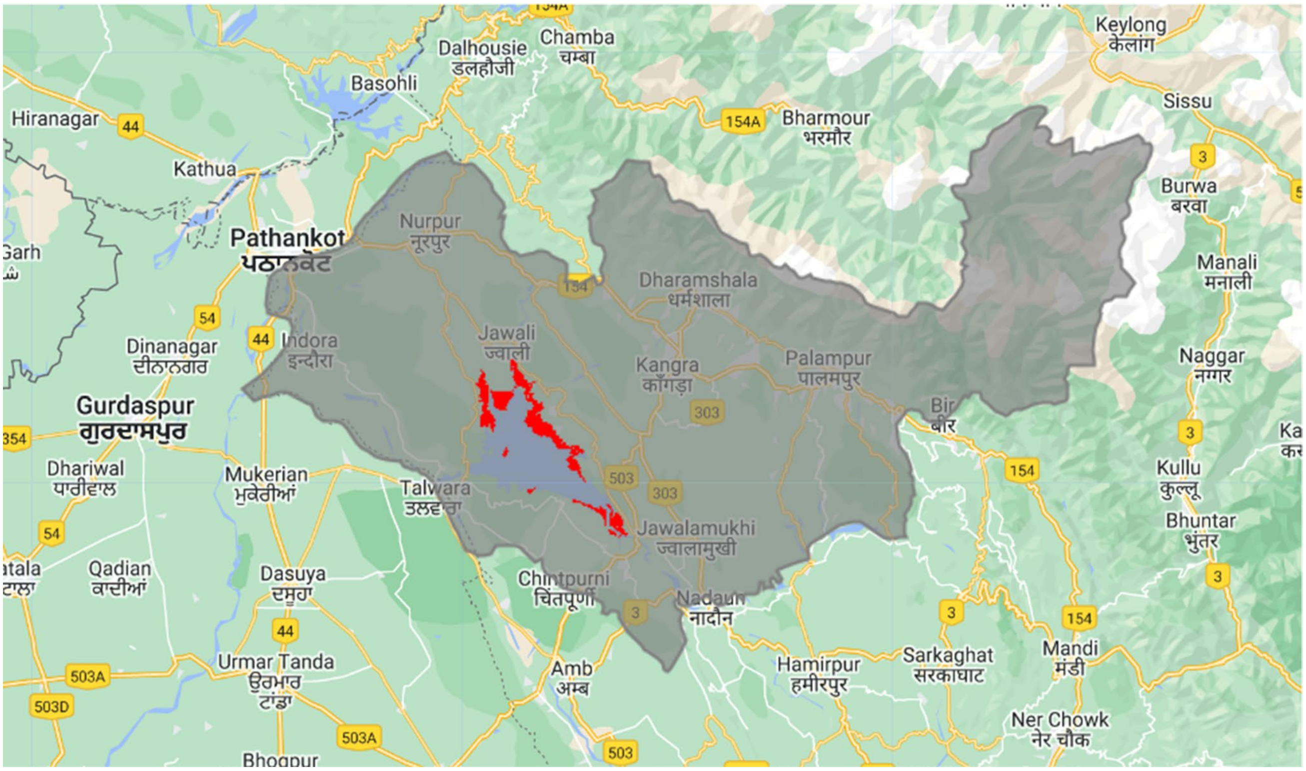


Fig. 8 Flooded Area in Red Colour

4 Conclusion

Himachal Pradesh saw an unprecedented amount of rainfall in June and July 2023, which resulted in exceptionally strong monsoon conditions from July 7 to July 10. Operating out of the Meteorological Centre in Shimla, the India Meteorological Department reported widespread, unusually heavy rainfall throughout the state during this time. Cloud cover often obstructs optical satellite data during the monsoon season, which has led to the investigation of alternate techniques for mapping floods.

This study used Sentinel-1 Synthetic Aperture Radar (SAR) data to map flood inundations almost instantly. SAR is a vital tool for monitoring and mapping flood events in real time because of its capacity to collect data in any weather, even during the most intense monsoons.

Flood management is made more comprehensive by the combination of the Refined Lee algorithm, Google Earth Engine (GEE), and SAR data. Together, these resources give us the ability to handle crises and lessen the effects of flooding. The ability of SAR data and GEE to map flood-prone areas is a testament to the remarkable convergence of human ingenuity and technological advancement.

To promptly detect flood occurrences, SAR data's capacity to pass through cloud cover and give real-time data regardless of weather conditions is essential. Authorities can respond more quickly, possibly saving lives and minimising property loss, by combining our flood mapping approach with the current early warning systems [21].

Our study's comprehensive flood extent maps help guide the construction of flood-resistant structures and the efficient use of land during the planning of infrastructure [22]. Planners and engineers can minimise the effects of flooding by designing infrastructure with features like raised roadways, flood barriers, and improved drainage systems that are unique to the demands of the location. This is made possible by their ability to identify flood-prone areas with high precision.

The research's findings can aid in the creation of comprehensive flood management laws and regulations. Authorities can create stronger legislative and institutional structures for disaster risk management that prioritise preparedness, mitigation, and recovery after a disaster by integrating scientific evidence into policy-making procedures [23].

The results of our study emphasise that to reduce the danger of flooding, integrated watershed management and strategic land use planning are essential. To improve community resilience against flooding, we advise policymakers to give priority to these areas. Prospective avenues for future study include using machine learning for flood prediction and utilising multi-sensor techniques in flood mapping. By protecting vulnerable areas, these initiatives may result in more precise and effective flood management plans.

In conclusion, combining Google Earth Engine with openly accessible SAR information proves to be a crucial tool for quickly and effectively mapping flooded areas. In addition to guaranteeing real-time analysis, the cloud-based platform leverages the potential of open data to offer a strong solution for efficient disaster response and mitigation strategies.

Author contributions Mr. Singh wrote the main manuscript while Dr. Rawat Corrected the GEE Cords and Finalized manuscript.

Data availability In this research all the used data are available in public domain and free for all at the Website of European space agency and USGS.

Competing interests The authors declare no competing interests.

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