Pavan Kumar · Haroon Sajjad
Bhagwan Singh Chaudhary
J. S. Rawat · Meenu Rani *Editors*

Remote Sensing and GIScience

Challenges and Future Directions

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ISBN 978-3-030-55091-2 ISBN 978-3-030-55092-9 (eBook)
https://doi.org/10.1007/978-3-030-55092-9

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

Foreword

Remote sensing (RS) has emerged as an important technique and tool that blends developments in computer science and Geographical Information System (GIS) for analyzing the various dimensions of the environment and adheres to its applications in almost every field. Remote sensing being cost and time effective is helpful in analyzing the temporal and spatial pattern of natural resources and distribution of population. The multispectral remote sensing datasets have provided effective assessment of natural resources and their management. These datasets are also promising in determining the population pattern, urban sprawl, and changes in land use/land cover. RS and GIScience have been proved effective tools for the scientific community to analyze spatial phenomena on Earth and consequently for policy formulation globally. However, certain challenges in handling large datasets and complex data formats still remain.

This book provides a comprehensive compilation of the use of remote sensing and GIS for different applications. Agriculture productivity, air pollution, habitat suitability mapping, assessment of vegetation vigor, as well as various data sets and their applications in assessment of natural resources, mapping the population pattern, and land use/land cover will help the readers to obtain insightful information about the complexity and challenges in their assessment. This book provides imperative assessment based on remote sensing technique for measuring the spatio-temporal variability of population, dynamics of land use, natural resources, and their sustainable management. I believe this work will help different stakeholders to understand different aspects of remote sensing along with the application of GIScience for various applications.

I congratulate the editors, the contributors' from different parts of the country, and the publisher for bringing out a timely publication depicting challenges and future directions in remote sensing and GIScience and hope that this important book shall serve as a reference for different institutions working in this area.

Vice-Chancellor, Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India

Prof. Arvind Kumar

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About the Editors

Pavan Kumar is a Faculty Member at the College of Horticulture and Forestry, Rani Lakshmi Bai Central Agricultural University, Jhansi, U.P., India. He obtained his Ph.D. degree from the Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi. Dr. Kumar completed his B.Sc. (Botany) and M.Sc. (Environmental Science) at Banaras Hindu University, Varanasi, India, and subsequently obtained Master's degree in Remote Sensing (M.Tech.) from Birla Institute of Technology, Mesra Ranchi, India. His current research interests include climate change and coastal studies. He is recipient of Innovation China National Academy Award for Remote Sensing. Dr. Kumar has published 50 research papers in national journals and authored a number of books. He has visited countries like the USA, France, the Netherlands, Italy, China, Indonesia, Brazil, and Malaysia for various academic/ scientific assignments, workshops, and conferences. Dr. Kumar is member of the International Association for Vegetation Science, USA and Institution of Geospatial and Remote Sensing, Malaysia.

Haroon Sajjad is Professor in the Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India. His present research interests include environmental management, sustainable development, watershed management, and applications of remote sensing and GIS. He authored four books and has published more than hundred research papers in journals of international repute. Prof. Sajjad has presented 50 research papers at national and international conferences. Ten scholars have been awarded doctoral degrees under his supervision. He is reviewer of many scientific research journals and member of various scientific bodies.

Bhagwan Singh Chaudhary is currently working as Professor and Chairman in the Department of Geophysics at Kurukshetra University, India, since December 2017. He is also Registrar (offg.) of Kurukshetra University since June 5, 2020. Prof. Chaudhary has also worked as Founder Registrar at Chaudhary Bansi Lal University, Bhiwani, from Aug. 2014 to Dec. 2017. He started his career as Scientist at Haryana Space Application Centre, Hisar, in 1990 and worked there till 2004. Prof. Chaudhary was awarded DAAD Fellowship at the University of Freiburg, Germany, from 1997 to 1999. He has been working in the domain of geospatial technology for natural resources for about 30 years and has published more than 70 research papers in various national and international journals/conferences. Prof. Chaudhary has visited many countries like the USA, the UK, Austria, Germany, France, the Netherlands, Switzerland, Poland, China, South Africa, Indonesia, Bangladesh, Sri Lanka, Nepal, and Thailand for various academic/scientific assignments and conferences.

J. S. Rawat is presently Director of the Centre of Excellence for Natural Resources Data Management System in Uttarakhand (COE NRDMS), Coordinator of M.Sc. Remote Sensing and GIS Course at Kumaun University, and Director of Uttarakhand Centre on Climate Change. He is a Gold Medalist of Kumaun University and was awarded Senior Fulbright Fellowship by the Council for International Exchange of Scholars, Washington, D. C., USA, in 1988. Prof. Rawat has published about 122 research papers in international/national journals/books; written 3 books; participated in 15 international conferences including in Canada, Germany, and China; and participated in 89 conferences/expert committee meetings in India.

Meenu Rani received her M. Tech. degree in Remote Sensing from Birla Institute of Technology, Ranchi, India. She is currently affiliated to the Department of Geography, Kumaun University, Nainital, Uttarakhand, India. Dr. Rani has worked on remote sensing applications as a Junior Research Fellow at HARSAC and as Research Associate at the Indian Council of Agricultural Research and GB Pant National Institute of Himalayan Environment and Sustainable Development. Dr. Rani has authored and co-authored several peer-reviewed scientific research papers and presented works at many national and international conferences including the USA, Italy, and China. She has been awarded with various fellowships from the International Association for Ecology, Future Earth Coast, and SCAR Scientific Research Programme. Dr. Rani received early career scientists achievement award in 2017 at Columbia University, New York, USA.

Part I
General

Introduction to Challenges and Future Directions in Remote Sensing and GIScience

Raihan Ahmed, Pavan Kumar, and Meenu Rani

Abstract This book provides an overview of remote sensing and GIScience (GIS) and their challenges and future directions. Modern technology like remote sensing and GIS with timely and accurate information helps to monitor and analyze a wide range of phenomena like water, vegetation, land, and human activities. Interdisciplinary studies are also noticed in human–environment interaction between stakeholders and decision makers for real world applications. Remote sensing data products and their limitations are also discussed in the book. To overcome this situation, artificial intelligence (AI), along with cloud computing and big data analytics, is the need of the hour. Decision support system based on the AI in remote sensing and GIS is key to the implementation of decision-making and planning in a sustainable manner. The book is segregated into 5 parts spreading over 15 chapters. Part I discusses the challenges and future direction of remote sensing and GIS in various fields. Chapters 2–5 in the second part are devoted to challenges in sustainable natural resources management. Various applications of remote sensing and GIS in urban growth management are presented in Chapters 6–9 of Part III. In Part IV, challenges and future directions in GIS have been discuss in Chapters 10–14 through GIS modeling. Part V devoted to one chapter deals with the GIS revolution in science and society.

Keywords Remote sensing · GIScience · Challenges and Future direction

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P. Kumar et al. (eds.), *Remote Sensing and GIScience*,
https://doi.org/10.1007/978-3-030-55092-9_1

Development of remote sensing and GIScience (GIS) is crucial for scientific exploration of the earth's system, such as hydrosphere, lithosphere and biosphere. The phenomenon of the earth's system such as natural and human-induced has much significance in today's world. Remote sensing and GIS are modern technologies with timely and accurate information. Information access through these technologies helps to monitor and analyze a wide range of phenomena like water, vegetation, land, and human activities. It also helps to explore the potential natural resources for human use. Therefore, it is being used widely in various disciplines and multidisciplinary subject areas for decision-making and problem-solving processes.

The human–environment interaction (HEI) plays a key role in the dynamics of global environmental system. HEI analysis uses disparate datasets for every particular study. However, there are some similarities between methods and techniques in remote sensing and GIS practitioners. It creates an inter-disciplinary study in HEI and collaboration between authors of various disciplines. Increased collaboration beyond academics is also seen nowadays by stakeholders and decision makers for real world applications. Remote sensing and GIS provide information through data mining and processing. Therefore, ground reference data inclusion in remote sensing and GIS are crucial for the relevance of every study.

In the era of industrialization and climate change, HEI deteriorates the earth's biosphere and its carbon and hydrological cycles. To overcome this problem, a large amount of data and processing power is required along with the decision-making system. This is the main challenge for remote sensing and GIS, which have large spectrum of data with various limitations. Remote sensing data products are available with various spatial, spectral, and temporal resolutions. Therefore, studies use site-specific data products to fulfill the need of the specific study. For example, temporal changes in urban land use need high spatial, which requires large storage of data with specific time interval. Therefore, storage as well as processing need time for this kind of research. Some studies need spectral resolution for identifying the objects. Hyperspectral remote sensing data products with high spectral resolution have provided satisfactory results for this kind of research.

Promising solutions for these challenges can be obtained with the help of cloud computing and big data analytics. It is obvious that artificial intelligence (AI), along with cloud computing and big data analytics, is the future of remote sensing and GIS. Decision support system based on AI in remote sensing and GIS is the key to the implementation of decision-making and planning in a sustainable manner. Visualization of spatial data in GIS is a way forward to achieve planning and decision-making for stakeholders. It helps decision makers to take action based on the data visualization through GIS, e.g., natural hazards, urban planning, environmental management, and crime. Prediction and modeling of natural hazards are extremely difficult in the real world due to its complex nature. Till date, there is no such method to predict the results with zero uncertainty. AI has achieved the deal with precision modeling for complex problems of the earth's system. It can analyze the different aspects with sufficient detail and iteration for a complex problem.

Google Earth Engine is a platform based on cloud computing to analyze the geospatial data. It has massive computational capabilities to analyze a large amount of spatial data in a short time period. The advantage of this platform is to analyze spatial data without storing them in personal computers. Therefore, it helps to process large scale studies such as those at regional and country levels with efficient results. An attempt has been made in this book by the contributors to evaluate the efficiency of remote sensing and GIS techniques through various studies. Chapters in this volume have been grouped into five parts: General, Challenges in Sustainable Natural Resources Management, Remote Sensing and GIScience in Urban Growth Management, Challenges and Future Directions in GIScience, and GIScience for Revolution in Science and Society. Part I deals with the usefulness of remote sensing and GIS in various field of study. It covers the applicability of remote sensing and GIS in HEI, natural hazards, and environmental management. The future of remote sensing and GIS in the light of AI, cloud computing, and big data analytics is also focused on in this part.

Part II deals with the Challenges in Sustainable Natural Resources Management. It comprises four chapters concentrating on flood, vegetation, landslide, and glacier retreat and their direct and indirect impact on natural resources. In chapter "Environmental and Livelihood Impact Assessment of 2013 Flash Flood in Alakananda and Mandakini River Valley, Uttarakhand (India) Using Environmental Evaluation System and Geospatial Techniques," Tripathi et al. made an attempt for environmental and livelihood impact assessment of 2013 disastrous flood in Mandakini valley. They used Landsat data product for preparing land use land cover (LULC) maps and the statistical changes were estimated in the respective LULC classes. The results showed significant changes in terms of LULC dynamics in the whole region. In chapter "Assessment of Vegetation Vigor Using Integrated Synthetic Aperture Radars," Sinha assessed the vegetation using Integrated Synthetic Aperture Radars (SAR). In the study, the author uses SAR data to estimate forest biomass. Study shows a suitable approach in assessing vegetation vigor from above ground biomass through SAR. In the chapter "Landslide Susceptibility Mapping using Bivariate Frequency Ratio Model and Geospatial Techniques: A Case from Karbi Anglong West District in ASSAM, India," Ahmed et al. made an attempt to prepare an inventory map of landslide susceptibility using geospatial technology and bivariate frequency ratio model for Karbi Anglong West district. The study revealed that frequency ratio model along with geospatial technique helped not only in identifying landslide prone areas but also proved to be instrumental in examining level of susceptibility. In the chapter "Retreating Glacier Dynamics Over the Last Quarter of a Century at Uttarakhand Region Using optical Sensors Time Series Data," Kalita et al. examined the retreating glacier dynamics over the last quarter of a century in Uttarakhand. In their study, they used optical remote sensing data products for examining the changes from 1994 to 2015 and changes detected for snow and vegetation were 1377 km^2 and 896 km^2, respectively. The study results showed the actual determination of glacier dynamics and its kinetic of change rate and how climate is impacting over snow and ice resources.

Part III deals with the Remote Sensing and GIScience in Urban Growth Management. It contains four chapters focusing on the impact of urbanization on agriculture, impervious built-up, building subsidence, and LULC for land resource development.

In the chapter "Studying the Impact of Urbanization on HYV Rice Fields at a Local Level Using Fine Resolution Temporal RISAT-1 Datasets," Roychowdhury and Bhanja assessed the Impact of urbanization on High Yielding Variety (HYV) rice fields at a local level. Their study estimates the HYV rice fields vulnerable to conversion due to non-farm uses around sprawling urban settlements. In the chapter "Identification of Impervious Built-Up Surface Features Using Resources at 2 LISS-III Based Novel Optical Built-Up Index," Santra et al. tried to identify the impervious built-up surface through built-up index. In their study, they used several built-up indices for comparison. Their newly developed Impervious Built-up Index shows the maximum accuracy, i.e., 92.33%. In the chapter "Subsidence Assessment of Building Blocks in Hanoi Urban Area from 2011 to 2014 Using TerraSAR-X and COSMO-SkyMed Images and PSInSAR," Anh et al. assessed building subsidence in Hanoi urban area from 2011 to 2014 by high resolution radar satellite images. Their results revealed that high precision leveling is the key to assess the accuracy of subsidence determination of buildings. In the chapter "Analysis of Land Use/Land Cover Mapping for Sustainable Land Resources Development of Hisar District, Haryana, India," Rani et al. mapped the LULC for sustainable land resource development in Hisar district. They used IRS/LANDSAT data products to analyze various land resource constraints by taking collateral information on soil types, groundwater quality, and depth along with geomorphological constraints.

Part IV deals with the challenges and future directions in GIScience. The part consists of five chapters concentrating on solar energy potential, rice growth stage mapping, habitat suitability mapping, air pollution modeling, and agricultural productivity mapping. In the chapter "A Spatial Investigation of the Feasibility of Solar Resource Energy Potential in Planning the Solar Cities of INDIA," Roychowdhury and Bhanja investigated the feasibility of solar resource energy potential in planning the solar cities of India. Their study focused on identifying solar hotspots of India and how the spatial distribution of solar energy resources accentuate or hinder the performance of the solar cities. The study also conducted a techno-economic feasibility using solar resource datasets derived from high resolution satellites. In the chapter "Mapping Rice Growth Stages Employing MODIS NDVI and ALOS AVNIR-2," Panuju et al. mapped rice growth stages using MODIS NDVI and ALOS AVNIR-2. They used time-series NDVI for growth-stage indication and five classifiers for mapping the growth stages. The study revealed the efficiency of neural network and support vector machine in mapping growth stages. In the chapter "Habitat Suitability Mapping of Sloth Bear (Melursusursinus) in the Sariska Tiger Reserve (India) Using a GIS-Based Fuzzy Analytical Hierarchy Process," Jain et al. mapped the habitat suitability of the sloth bear (Melursusursinus) in the Sariska Tiger Reserve (India) using a GIS-based fuzzy analytical hierarchy process. Nine parameters have been used for assessing sloth bear habitat suitability in the study. Their suitability classes were validated through zonal statistics of beat wise habitat intensity data of sloth bear in the Reserve. In the chapter "Estimation of Air Pollution Using Regression Modelling Approach for Mumbai Region Maharashtra, India," Kumari et al. estimated air pollution using regression model for Mumbai. The study was an integrated approach to attain the spatio-temporal attributes of air pollution index of particulate matter (PM_{10} and $PM_{2.5}$) and trace gas (O_3, NO_2, and CO) pollutants in Mumbai. They used spatial variation of API for different air pollutants to simulate the Inverse Distance Weighted method of interpolation. In the chapter "Mapping of Agriculture Productivity Variability for the SAARC Nations in Response to Climate Change Scenario for the Year 2050," Singh et al. mapped the agriculture productivity variability for the SAARC nations in response to climate change scenario for the year 2050. They assessed the impacts of climate change on agriculture productivity net primary productivity using Joint UK Land Environment Simulator. Results of the study revealed a slight decrease in productivity with spatial variability across the SAARC nations.

Part V deals with the GIScience for Revolution in Science and Society. It comprises one chapter focused on the revolution of GIS in science and society for solving the future challenges in spatial information. In the chapter "Future Direction of GIScience for Revolution in Science and Society Over the Past Twenty Years," Lal et al. emphasized the need of GIS in society for problem-solving with the help of spatial data and modeling as GIS plays a vital role in monitoring the physical characteristics of the earth's surface over decades. The advancement of GIS technologies, specifically in GIS geomorphologic mapping, has provided us with core data of landform development, including those due to geophysical or climatic events such as earthquake, volcanic eruption, landslides, and cyclone.

Part II
Challenges in Sustainable Natural Resources Management

Environmental and Livelihood Impact Assessment of 2013 Flash Flood in Alakananda and Mandakini River Valley, Uttarakhand (India), Using Environmental Evaluation System and Geospatial Techniques

Shruti Tripathi, G. Areendran, N. C. Gupta, Krishna Raj, and Mehebub Sahana

Abstract India has been historically susceptible to natural disasters due to its unique geo-climatic conditions in which the Himalayan ecosystem is very fragile and a little disturbance can cause harmful effects. The present work is an attempt to assess the environmental and livelihood impact of the 2013 flood in Mandakini valley, Uttarakhand (India), using geospatial techniques and an environmental evaluation system. The land use land cover (LULC) maps for the years 2011, 2014, and 2017 (Alaknanda basin) and 1997, 2011, and 2017 (Mandakini basin) were prepared using Landsat satellite imageries, and the statistical changes were estimated in the respective LULC classes derived. The results showed significant changes in terms of LULC dynamics in the whole region. Further, to analyze changes in vegetation cover in the region, Normalized Difference Vegetation Index was calculated, depicting the overall decrease in vegetation cover. By using Battelle Columbus method of environmental evaluation system, the impact of the flood on ecological and cultural aesthetics and human interests, with and without the disaster is also derived. A questionnaire-based survey was conducted in Gaurikund and Kedarnath to assess the repercussions of the flood on the livelihoods of inhabitants. It showed that the stoppage of tourism-based livelihood activities, which were critical to the local people, deems it necessary to map the footprint of the flood on livelihood generation activities. The overall result of this study is that there are significant impacts of flood on both the environment and people residing in the region, and anthropogenic activities were major contributors to the catastrophe. The major outcomes of this analysis will help in creating the baseline data for major

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P. Kumar et al. (eds.), *Remote Sensing and GIScience*,
https://doi.org/10.1007/978-3-030-55092-9_2

disastrous studies in India and also support sustainable management strategies in response to these extreme events.

Keywords Mandakini valley · Geospatial techniques · LULC · Livelihood framework · NDVI · Battelle Columbus method

1 Introduction

India is highly prone to floods, droughts, cyclones, and earthquakes. The frequency of avalanches, forest fire, and landslides is high in the Himalayan region of northern India (Sahana and Sajjad 2017; Sahana et al. 2018; Khatun et al. 2018; Areendran et al. 2020). In India, 25 out of 36 states/union territories are more vulnerable to natural calamities. Around 50 million people in the country are affected by one or the other disaster every year on an average, besides the loss of property worth several million (Sharma 2005). The Himalayan region is seismically and tectonically active, geologically unstable, remotely located and ecologically most fragile (Sati 2008). In successive years, the same area encounters one or more disasters. Many people live in these disaster-prone areas and generate a livelihood from available natural resources (Sahana and Sajjad 2019). The World Bank has stated that a large number of people who come under the extremely poor section live on “insubstantial” lands, including forest ecosystems, slopes, and poor soils (World Bank 2003, p. xvi). Around 240 million people live in forested areas, constituting 18.5% of the 1.3 billion people living in environmentally fragile lands (World Bank 2003, p. 60). If all these natural disasters could be predicted and prevented with a state of preparedness and ability to respond quickly to the calamity, it can considerably cut or mitigate the loss of life and property.

In June 2013, heavy rainfall triggered flash flooding and landslides throughout the Indian Himalayan state of Uttarakhand, which killed more than 6000 people. The destruction and fatalities resulted directly from a lake outburst and debris flow originating from above the village of Kedarnath (Allen et al. 2016). The heavy downpour (>400 mm) created a huge flash flood causing damage to agricultural fields, settlements, and infrastructure and loss of human and animal lives, and widespread devastation of natural resources in different parts of the state (Uttarakhand). Around 100,000 pilgrims and tourists were stuck because of the destruction of trekking routes and roads until civic and military authorities arrived and evacuated them (Martha et al. 2015; Sharma and Tyagi 2013). There were two landslides that occurred in Kedarnath on the 16th of (month?), one in the North East and the other in the North West, both originating around the glacier. Debris flow was initiated by the landslide in the North East that ran down en-route. In the North West, conditions are very different. Landslides and moraines left by retreating glaciers blocked drainage and allowed the formation of a pool that overtopped the moraine barrier and led to a catastrophic breach (Sahana and Sajjad 2017). This released high volumes of water downstream in the low-lying area, causing a flash flood (Patley

2013). The reason for maximum devastation in Kedarnath valley was the breach of the moraine-dammed Chorabari Lake that was situated 1.5 km above Kedarnath town from where the unconsolidated moraine debris was deposited and breached down to the town. Landslides due to floods damaged several houses and killed many people who were trapped in these structures. Entire villages and settlements such as Gaurikund and the market town of Rambada got damaged, while the market town of Sonprayag suffered heavy damage and loss of lives (Indian Disaster Report 2013). The total roof area in Kedarnath before the disaster was 37,299 m^2 (259 structures), 44.2% of which were completely destroyed and 26.7% were partly damaged, representing 138 and 56 structures, respectively. Around 26.9% of the roof area of partly destroyed structures was gone. Only the Kedarnath temple emerged as an unharmed structure in this disaster (Das et al. 2015).

The study of the socio-economic impact of the disaster consists of both qualitative and quantitative approaches. Quantitative household questionnaires and qualitative key informant's interviews were used to collect data. Among all-natural disasters, floods are the most frequent and 33 million people were affected by floods from 1953 to 2000 (Syyed et al. 2013; Mohapatra and Singh 2003). A study was conducted by Belaid (2003) to show urban-rural land use change using remote sensing and GIS and concluded that these technologies together with secondary data can be used to assist decision-makers to prepare future plans in order to find out the appropriate solution to urbanization (Syyed et al. 2013). Four hundred and eighty people inhabit Kedarnath during the summer months and also from neighboring towns. People come every year in search of livelihood and leave during the winters like the rest of the residents. Roughly, around 5000 people arrive and leave daily during pilgrimage time. People who live in the town earn through tourist-related activities during yatra time. This is also because of the harsh winter season (https://www.yatra.com/india-tourism/Kedarnath/people). In 2012, the number of pilgrims reached a high of 259,900 (by a tour of India) and they provide a variety of income-generating sources. People have been engaged in tourism-based activities for generations. So, this flood had snatched their main income-generating source for almost 2–3 years. Many researchers tried to map the impact of the flood on livelihood in other disasters like Pakistan which faced a tragic flood in 2010 that affected more than 20.1 million people in the whole country (Ashraf et al. 2013). Ashraf et al. in 2013 conducted a study in southern Punjab to explore the effect of floods on food security and the livelihood of rural communities. Results revealed that flood affected the natural capitals (land, irrigation, orchards, and livestock) pushing the income-generating sources into darkness. Flood becomes a hazard only where human encroachment occurs in flood-prone areas (Smith and Ward 1998; Sahana et al. 2015; Sahana and Patel 2019). A study that was undertaken in Scotland suggests that social impacts are linked to the level of wellbeing of individuals, communities, and societies. It also includes aspects that are related to education and literacy, the existence of security and peace, basic human rights, good governance, positive traditional value, social equity, custom and ideological belief, knowledge structure, and overall organization systems. Some groups are more vulnerable to floods than others like the poor and under-privileged (Nott 2006). Poor people are more vulnerable to disasters because they lack physical, social, and knowledge-based resources to respond to and prepare for threats. Because they are poor, they are more vulnerable, and hence are at greater risk in the face of hazard, leading to disasters (Das et al. 2005; Rehman et al. 2019; Bjarstig and Stens 2018). The loss in case of flooding has many dimensions; in addition to economic loss and loss of life or injury, there may be irreversible loss of land and of history of cultural ecological valuables (Muis et al. 2015). Among natural hazards, flooding claimed more lives than any other single hazard from 1986 to 1995. Flooding accounted for 31% of global economic losses from natural catastrophes and 55% causalities (De Bruin et al. 2014).

These conditions lead to food insecurities and food deficits as people use contaminated commodities, especially water (Sahana et al. 2020). So, taking all this into consideration, this paper's major focus is on the impact of the flood on the environment and livelihood of the people involved in Kedarnath yatra every year. Other papers tried to discover the reason for the floods and damage caused. It is very important to map the footprint of the flood on livelihoods. It will help policymakers and institutions help these vulnerable people and make their livelihood sustainable.

2 Study Area

Uttarakhand is predominantly a hill state, having international boundaries with China in the north and Nepal in the east. The Himalayan region in Uttarakhand (~53,483 km^2) lies between Kali Ganga (bordering with Nepal) and Tons-Yamuna (bordering with Himachal Pradesh). Around 10% of the total area of Uttarakhand is covered by snow, ice, and glaciers. These are the perennial source of water for four major river systems, viz. Yamuna, Bhagirathi, Alaknanda, and Kali (Singh and Rawat 2011; Dobhal et al. 2013). In Uttarakhand, 4 districts were majorly affected by the flood in which Rudraprayag district saw greater loss in terms of lives and property (NIDM Report 2013). Many lost their family members, houses, jobs, shelter, and so on. In this study, Mandakini valley was selected to understand the effects of the disaster. Figure 1 shows the study site.

Alaknanda basin is located at 30.1333° latitude and 78.6029° longitude. Its main tributaries are Mandakini, Nandakini, and Pinder and considered to rise at the foot of the Satopath glacier in Uttarakhand (Sati 2009). The Alaknanda river basin is sandwiched between the crystalline? of lesser and higher Himalayas. It is characterized by high-grade metamorphic rocks of higher Himalayan crystalline in the north and lesser Himalayan sequence in the south (Metcalfe 1993; Valdiya et al. 2000; Valdiya 1995). High mountainous ranges in the northern part, particularly in the north eastern and north western part of the watersheds, are covered with snow-fields or glaciers. The rivers of Alaknanda basin are perennial, since runoff in these rivers is controlled by both precipitation and glacial melt (Sati 2009).

River Mandakini, the main river of the Alaknanda basin and valley, is a major tributary of River Alaknanda and originates from the Chorabari Glacier, situated just

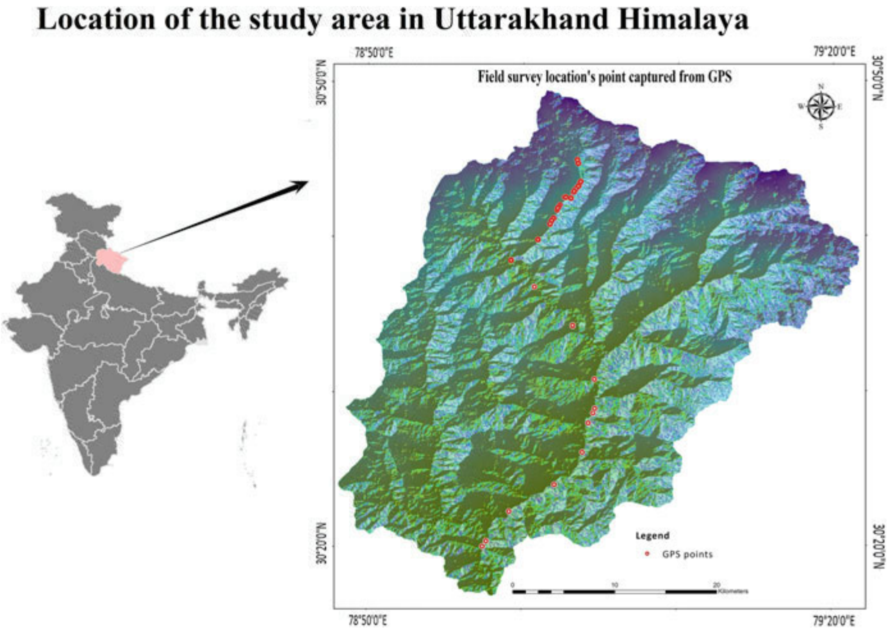

Fig. 1 Location map of Alaknanda and Mandakini basin and the GPS points collected during the field survey

2 km above Shri Kedarnath shrine. The Shri Kedarnath town is situated in the Central Himalayas (30° 44′ 6.7″ N; 79° 04′ 1″E) in the Mandakini River valley. The catchment area is situated in the glacier-modified U-shaped valley; the altitude ranges from 1700 m asl to 6578 m asl. Such a variation in the altitude provides various landscapes. BhartKhunta (6578 m), Kedarnath (6940 m), Mahalaya peak (5970 m), and Hanuman top (5320 m) are major peaks in the area. The climate of the region largely depends on altitude as elevation ranges between 1600 m and 6500 m asl. Winter is from mid-October to April. The slope of the study area lies between 30 and 60° and toward the South East aspect. The alpine habitat usually starts at timberline and is characterized by the complete absence of trees. The soil in Kedarnath valley is dark brown on the surface and yellowish-brown below (Singh et al. 1986). Floristic composition shows mixed forests of rhododendron, *Quercusleuco trichophora* (Banj), *Quercus floribunda* (Moru), and *Quercusseme carpifolia* (Kharsu), *Buxus wallichiana (papri), Acer* spp. (Kaijal), *Betula alnoides* (Katbhuj), and *Alnus nepalensis* (Utis) up to an elevation and the rest are alpine pastures. This area has traditionally occupied an important position in the socio-cultural, spiritual, and medicinal arena of rural and tribal lives of Uttarakhand (Rawat 2016). According to the report of Climate Himalaya on plausible reasons for this flood, the root of the disaster is in the Chorabari Glacier located in Mandakini valley. This is why Mandakini valley was chosen as the study area to access environmental damage and its impact on the livelihoods of inhabitants.

3 Material and Methodology

3.1 Data Collection

Materials that were used during the study are various websites from the internet like Earth Explorer, Bhuvan, and Diva GIS; GIS software like ERDAS Imagine and Arcmap10; national and international journals, a questionnaire for the assessment of damage and pre-disaster livelihood options. Satellite images used in this study are mentioned in Table 1.

3.2 Data Collection for the Survey

Field survey was conducted to assess the impact of the flood on socio-economic parameters of the valley's residents. For that purpose, livelihood's 5 capitals were studied, i.e., physical, natural, financial, health, and social capitals. Sample data were collected through the questionnaire-based survey in Gaurikund village, en-route to Kedarnath temple and in Kedarnathghati. Figure 1 shows the GPS points that were selected by random selection method to select the interviewees. It was learned that, in Mandakini valley, en-route Kedarnath temple, many people earn their livelihood from various food stalls or carrying people to the temple using horses and on their back. Figure 2 shows various types of livelihoods in which inhabitants are engaged in.

Table. 1 Satellite images used in this study

S. no.	Name of satellite	Year	Resolution
For Alaknanda basin			
1.	Landsat 5	January 2011	30 m
2.	Landsat 8	January 2014	30 m
3.	Landsat 8	January 2017	30 m
For Mandakini basin			
1.	Landsat 5	January, 1997	30 m
2.	Landsat 5	January 2011	30 m
3.	Landsat 8	June 2013	30 m
4.	Landsat 8	January 2014	30 m
5.	Landsat 8	January 2017	30 m
For rainfall			
1.	TRMM (Netcdf)	2001–2016 (June)	0.25°

Fig. 2 Field photographs of livelihood types in the Kedarnath and Gaurikund regions

3.3 Analysis of the Satellite Images for Impacts of Flood

3.3.1 Image Acquisition

Satellite images that were used in this study are mentioned in Table 1. These images were downloaded from USGS Earth Explorer official site and Bhuvan. These imageries are freely available on the mentioned portals.

3.3.2 Georectification

The topographical maps were georectified by selecting ground control points throughout the area projected in the projection system geographic (Lat/long) with spheroid and datum being WGS 84. From georeferenced imageries, the study area was obtained through a subset using the AOI boundary vector file (Hughes et al. 2006).

3.3.3 Image Extraction (Subset/Mosaicking)

Satellite images that were downloaded from the Earth Explorer website were opened in ARC GIS, and the area of interest was extracted from that image to use for further study. However, in our case, our area of interest was spread across two satellite images. So, we used the Mosaic tool in ERDAS Imagine to mosaic the images and then extracted our study of area from it.

3.3.4 Image Classification

The purpose of image classification was to categorize all pixels in an image into different land cover classes. Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands to classify each pixel. This process assigns each pixel in an image to a particular class or theme based on the statistical characteristics of the pixel brightness values (Guo and Zhang 2009).

3.3.5 Unsupervised Classification

In unsupervised classification, outcomes are based on the software analysis of an image without the user providing sample classes (Source Extension.org). In this type of classification, spectral classes were grouped first into 85 classes, based solely on the numerical information in the data. The classes that result from unsupervised classification are spectral classes distinguishing urban from the open area, agriculture from forest class, etc., and is often difficult because of similar reflectance patterns. Therefore, for more accurate classification, the number of classes classified initially was more. References like Google Earth maps prepared by other sources were used to recode and clean the initially classified image. AOI tools like polygon/polyline were used for cleaning.

3.3.6 Digitization (for Vector Layer)

Different features like roads, rivers, towns, and soil types were extracted from scanned and georeferenced images using ArcGIS 10 digitization tools. Features like water bodies and settlements were extracted using Google Earth. The files obtained were in .kmz format, which were converted to shapefile using ArcGIS 10 conversion tools. Digitization was carried out manually. All the features were digitized as point, line, or polygon. Figure 3 shows the methodological framework used in this study.

3.4 Environmental Impact Assessment of Flood

Many research papers used Land Use Land Cover (LULC) analysis to assess the impact of flood on environmental settings and on human settlements (Sinha 1998; Ferrari et al. 2009). The method described in Fig. 4 was used to generate the LULC. We first downloaded the satellite images that are mentioned in Table 1 study area and then digitized and classified the post-flood-affected area in Uttarakhand. After

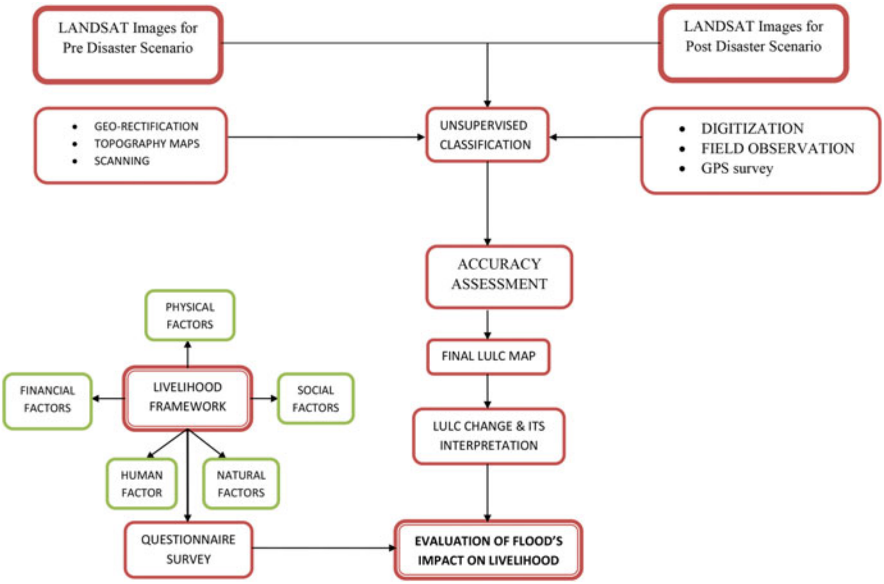

Fig. 3 Methodological framework used in this study

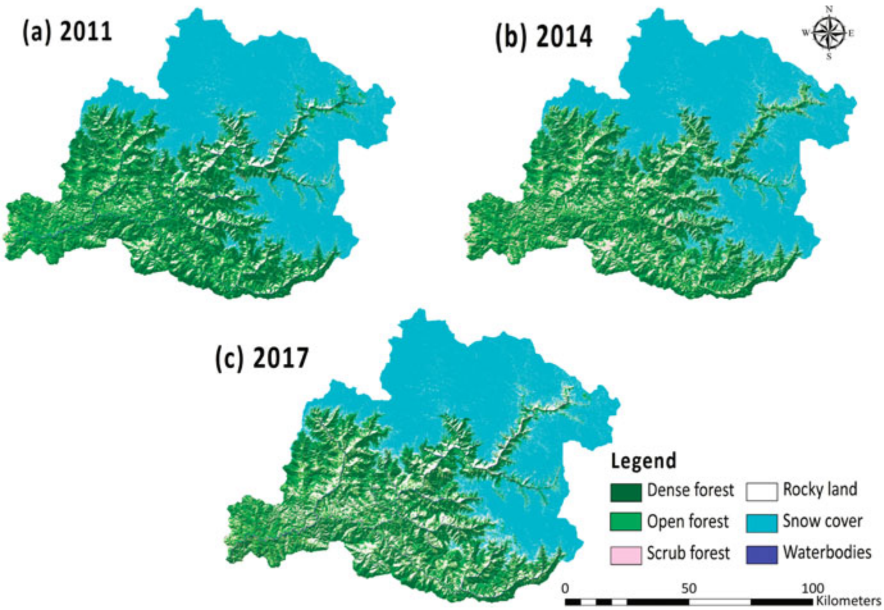

Fig. 4 Land use land cover pattern of Alaknanda basin (**a**) 2011, (**b**) 2014, and (**c**) 2017

that, we compared it with pre-disaster images to analyze the most to least affected areas. Landsat 8 images were used to digitize the flood-affected area with the help of data that was taken from the Bhuvan portal. Using Google Earth, roads, agricultural land, and settlements were digitized and then compared with flood-affected areas to analyze the damage caused by this flood in Mandakini valley.

We used the **Battelle Columbus** method for environmental impact assessment to evaluate environmental settings before and after the disaster. Battelle method is a quantitative method where 78 measurable environmental parameters are divided into 4 categories: environmental contamination, ecology, aesthetics, and human interest. In this method, 2 steps are involved; first is to convert parametric estimates into an environmental quality (EQ) scale that ranges between 0 and 1, where 0 denotes very bad quality and 1 denotes good quality. The second step is the multiplication of EQ values with the respective parameter importance unit values to obtain environmental impact units (EIU) for each parameter. Composite score is obtained by the addition of all EIU values. The total environmental impact is calculated by evaluating the expected future condition of the EQ with and without the project (Syyed et al. 2013).

$$\mathrm{E1} = \sum\nolimits_{i=1}^{m} (Vi)1Wi - \sum\nolimits_{i=1}^{m} (Vi)2Wi \tag{1}$$

Where

E_1 = Environmental impact
$(V_i)_1$ = Value in the EQ of parameter i with a project.
$(V_i)_2$ = Value in EQ of parameter i without a project.
W_i = Relative weight (importance) of parameter i
m = Total number of parameters

To do this, a checklist with all environmental parameters was made and assessed during the field visit and compared by weightage underlined in the Battelle method.

3.5 Normalized Difference Vegetation Index (NDVI)

This is a numerical indicator that uses the red and near-infrared spectral bands. NDVI is highly associated with **vegetation content**. High NDVI values correspond to areas that reflect more in the near-infrared spectrum. Higher reflectance in the near-infrared correspond to **dense and healthy vegetation**.

$$\mathrm{NDVI} = \mathrm{Band5} - \mathrm{Band\ 4/Band\ 5} + \mathrm{Band4\ (using\ Landsat\ 8\ data)} \tag{2}$$