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Haroon Sajjad · Lubna Siddiqui ·
Atiqur Rahman · Mary Tahir ·
Masood Ahsan Siddiqui *Editors*

Challenges of Disasters in Asia

Vulnerability, Adaptation and Resilience

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Editors
Haroon Sajjad
Department of Geography
Jamia Millia Islamia
New Delhi, Delhi, India

Atiqur Rahman
Department of Geography
Jamia Millia Islamia
New Delhi, Delhi, India

Masood Ahsan Siddiqui
Department of Geography
Jamia Millia Islamia
New Delhi, Delhi, India

Lubna Siddiqui
Department of Geography
Jamia Millia Islamia
New Delhi, Delhi, India

Mary Tahir
Department of Geography
Jamia Millia Islamia
New Delhi, Delhi, India

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In dedication to those who have been affected by the unprecedented pandemic—COVID 19 and disasters

Foreword

Not only is Asia the most highly populated continent, but it is also threatened by an extraordinarily wide variety of tropical and extra-tropical hazards, many of which produce impacts of high magnitude. In mountain zones, in particular, geophysical and meteorological hazards frequently overlap. In metropolitan areas, vast populations are at risk of a range of threats and hazards that grow ever more complex and pervasive as society becomes more highly interdependent. Cascading effects threaten fragile infrastructure and can lead to the proliferation of impacts far beyond their points of initiation.

Vulnerability is the key to understanding disasters and is likely to be one of the most enduring concepts in the pursuit of greater safety. Such is the variety of the human condition that resilience is not quite the opposite of vulnerability, as the two can, in fact, coexist amid the complexity of modern social and economic life. Vulnerability is expressed in human society through a series of categories: physical, social, economic, psychological, institutional, economic and so on. Beyond this, there is a need to achieve a more holistic approach that transcends the categories by extending disaster risk reduction to tackle the context in which disaster vulnerability is generated. Confronted with climate change and the spectre of technological breakdown, adaptation processes will have to be improved substantially in the future in order to provide a fairer, more equitable distribution of safety and security to the people of Asia and the world.

Over the last half century, the practical study of disasters has grown enormously, and with it, there have been substantial improvements in preparedness and response capacity. In Asia, there is a new spirit of collaboration and a renewed desire to share knowledge and expertise. This book provides a wide variety of examples of how research is contributing to disaster risk reduction in the Asian continent. Geophysical and meteorological hazards threaten lives, livelihoods, health, homes and food security, but there are solutions, many of which are described in the chapters of the book. I commend it to readers as a good source of knowledge and inspiration for disaster risk reduction in the Asian context.

David E. Alexander

David E. Alexander, Ph.D.
Risk and Disaster Reduction
University College London
London, UK

Preface

Disasters pose threats to social, economic and ecological environments. Millions of people globally are affected by natural and human-induced disasters. Nearly 90% people residing in countries exposed to natural hazards are experiencing extreme impoverishment due to the subsequent disaster shocks. Every year these disasters also push around 25 million people into poverty and cause economic losses of $100 billion. Inter-governmental Panel on Climate Change (IPCC) defines disasters as the stern changes in the normal functioning of society or community to the hazardous physical events after interacting with the social conditions resulting in huge environmental, social and economic losses that need quick response and effective support for recovery. Climate change has been identified as the major determinant of changes in the global conditions and alteration in the normalcy of the environmental functioning. The outcomes of these changes are increased in the frequency of extreme weather events including droughts, floods, sea level rise, heat waves and cyclones in fragile ecosystems. Such changes are accelerating the vulnerability of the socio-ecological system and tend to put pressure on the socio-economic conditions. Recently, COVID-19 has emerged as a global biological hazard with unprecedented pressure on health systems and made communities vulnerable. Diversity of the implications has hindered the treatment and affected the global healthcare system. Factual evidences on the virus are still lacking in actual representation of the ground realities. Low-income economies are experiencing health complications due to high population, low testing rates and inadequate clinical measures adding to already otherwise vulnerable status. These concerns have created realization about the effective clinical and health measures for limiting the further outbreak of the virus.

Vulnerability reflects the inability of a system or individual to cope with the impacts of anthropogenic and natural disasters. It arises from the physical, environmental, social and economic factors. Earliest attempts for analyzing vulnerability to disaster were found associated with identifying the factors leading to vulnerability of socio-ecological system. Later on, World Meteorological Organization during 1980s has revealed relationship between the climate variability and vulnerability. Climate variability refers to the increase in extreme weather events and intense climate phenomena due to short-term fluctuations in the meteorological variables.

Degree of vulnerability and resilience vary spatially and require effective modeling approach to analyze the susceptibility of the region. Earliest attempts on vulnerability assessment were carried out using Pressure and Release (PAR) and Risk Hazard (RH) models. Vulnerability to climate change was immensely discussed by the scientific community during 1990s. Concept of vulnerability later expanded including robustness, risk, exposure, adaptation and sensitivity. Thus, integrated approach was emphasized in disaster vulnerability assessment.

Response mechanism is an integral part of disaster risk reduction. It is essential to articulate the interaction of human and natural systems. Resilience in other way helps in overcoming the hardships. Mitigation and adaptation help in dealing with the climate change implication through cooperation and effectual policy at various scales with integrated response. Adaptation and mitigation are interrelated approaches effective in managing and reducing disaster risk. In disaster-prone nations, financial relief, effectual response strategies, preparedness, adaptation and enhancing resilience are immensely significant. Promoting awareness among vulnerable communities, response mechanism, enhancing resilience and adaptative capacity are essential components of disaster risk reduction. Various challenges are accompanied with disasters including inefficient planning, unstable infrastructural set up and inadequate financial support. One of the challenges associated with disasters is ensuring the provision of relief and related operations as per the intensity of the disasters. Man-made disasters are often accompanied with huge humanitarian and economic crisis. Such disasters are identified to be more destructive in case of developing rural economies. Making the healthcare system resilient is another concern to reduce the risk and achieve normalcy to disasters. Effective mitigation, proactive measure and effective post-disaster planning may help in overcoming these challenges.

The book has been divided into four parts and spreads over 27 chapters. The Part I deals with the impact and assessment of hazards. Part II is devoted to socio-economic and ecological vulnerability to disasters. In Part III, an attempt has been made to examine adaptation while Part IV dealt with resilience. In chapter "Probabilistic Seismic Hazard Assessment for the Frontal Part of the Mishmi Hills, India and Its Role in Disaster Management": Bijoylakshmi Gogoi et al. assessed probabilistic seismic hazard probabilistic for the frontal part of the Mishmi hills in India, and its role in disaster management. Their finding revealed that the highly hazardous zones are mainly distributed in the northeastern part of the area under investigation. In chapter "Assessment of Desertification and Land Degradation Vulnerability in Humid Tropics and Sub-tropical Regions of India Using Remote Sensing and GIS Techniques": S. Kaliraj et al. used the GIS-based DVI (Desertification Vulnerability Index) model for mapping and assessment of potential vulnerability to desertification and land degradation in the two districts lying in humid tropics and sub-tropics. Their findings revealed land degradation due to increased anthropogenic activities resulting in adverse impacts on environmental ecosystems. In chapter "Analysis of Diversified Impact of COVID-19 Pandemic Across the Indian States": Alpana Srisvastav analyzed diversified impact of COVID-19 pandemic across the Indian states. Her analysis revealed that Maharashtra was the worst hit state whereas north-eastern and hill states fared better, and concluded that poor health infrastructure and manpower, poverty, unhygienic living condition worsened the impacts of the pandemic. In chapter "Spatio-temporal Analysis of Seasonal Drought Pattern Using Vegetation Condition Index in Latur District": Shahfahad et al. analyzed spatio-temporal variation in drought pattern using remote sensing data. Wide variations occurred in the drought pattern in both the monsoon and post-monsoon seasons, and their findings can help in the drought management and planning in the study area. In chapter "Sea Level Rise and Impact on Moushuni Island of Sundarban Delta (West bengal)—A Geospatial-Based Approach": Atashi Jana and Gouri Sankar Bhunia have examined the impact of sea-level rise on Moushuni Island of the Indian Sundarban Delta. Their study revealed a rapid shifting of the shoreline on the island, resulting in progressive reduction in land area with the breaching of embankments. In chapter "Mapping of Affected Areas by Extreme Weather Events in *Kanda Tehsil* of *Bageshwar* District by GIS and RS Technique": Meenakshi Goswami mapped affected areas by extreme weather events in Kanda Tehsil of Bageshwar district in Uttarakhand. She concluded that the GIS and remote sensing technology have been very effective in the disaster mapping and disaster management with the help of demarcation and mapping of disaster affected areas. In chapter "Household-Based Approach to Assess the Impact of River Bank Erosion on the Socio-economic Condition of People: A Case Study of Lower Ganga Plain": Md Nawaj Sarif et al. assessed the impact of riverbank erosion on the socio-economic status of the lower Ganga plain. They observed greater variability and different impacts on several spheres of life. In chapter "Landslide Susceptibility Mapping of East Sikkim Employing AHP Method": Md Nawazuzzoha et al. employed analytic hierarchy process to map landslide susceptibility in the east Sikkim, India. They found satisfactory result and congruent with the landslide inventory maps. In chapter "Socio-Environmental Vulnerability of Agriculture Communities to Climate Change in Western Himalaya: A Household-Level Review": Neha Chauhan et al. review available literatures on socio-environmental vulnerability of agricultural communities to climate change in the western Himalayas. Their review emphasized that majority of the articles focused on a single stressor—climate change for vulnerability. Though the number of literatures is growing rapidly, holistic approaches and multi-level assessment are lacking. In chapter "Application of Mike 11 for One-Dimensional GLOF Modeling of a Rapidly Expanding Dalung Proglacial Lake, Indus River Basin, Western Himalaya": Riyaz Ahmad Mir et al. employed the Mike 11 model for one-dimensional GLOF modeling of the Dalung Proglacial Lake (DPL) in the Western Himalayas. Their study revealed that the DPL has been characterized as a potentially dangerous lake based on the type of lake and its volume, rate of lake formation and growth, position of lake, dam condition, conditions of associated mother glacier, morphometric characteristics of glacier, physical conditions of the surrounding area and situation down the valley, henceforth; detailed field investigation and regular monitoring of the lake is recommended. In chapter "Hybrid Tree-Based Wetland Vulnerability Modelling": Swades Pal and Satyajit Paul applied machine learning algorithms to model the wetland vulnerability. Of the different ML-based models, the Gradient Boosting Classification Model (GBM), and AdaBoosting Classification Model (ADB) exhibit more prediction capability.

The study recommends tree-based ML algorithms for such or similar works. In chapter "Spatio-temporal Analysis of Land Use / Land Cover Change Using STAR Method in Kolkata Urban Agglomeration": SK Mohibul et al. carried out the spatio-temporal analysis the landuse-landcover changes in the Kolkata Urban Agglomeration. The study observed that LULC change is mostly occurred along the transport routes and the existing urban fringe areas. The striking loss of natural wetland and vegetation cover coexists with an increase in built-up cover, hence unplanned urban growth. In chapter "Vulnerability Assessment of COVID Epidemic for Management and Strategic Plan: A Geospatial-Based Solution": Gouri Sankar Bhunia used geospatial technology to assess vulnerability of COVID pandemic for management and strategic plan. His study found correlations between vulnerability and the current incidence rate of COVID-19 intensity at the district level. In chapter "Auto-generated Gravity Canal Routes for Flood Mitigation and Groundwater Rejuvenation: A Study in Damodar–Barakar River Basin, India": Soumita Sengupta et al. made an attempt study to divert the excess surface runoff by a Canal Routing Model (CRM) and discharge the transported water to suitable groundwater recharge zones by performing the Site Suitability Model for Canal Outfall. The study suggested three suitable gravity canal routes to transport the surface water and three suitable groundwater recharge zones. In chapter "Assessing the Impact of Disasters and Adaptation Strategies in Sundarban Biosphere Reserve, India: A Household Level Analysis": Mehebub Sahana et al. made an attempt to assess the impact of disasters and its adaptation strategies in the Sundarban Biosphere Reserve (SBR), India through a cogent a household level field survey. Findings of the study indicated that the ex-situ out migration was the most preferred and effective adaptation strategy in the coastal blocks of SBR. Alternative fish activities and prawn cultivation are the other preferable in-situ adaptation measures adopted by the local communities. In chapter "Forest Fires in Tropical Deciduous Forests—A Precursor to Anticipatory Adaptation Framework": Jayshree Das and P K Joshi carried out a scoping study on forest fires in Tropical deciduous forests. They remarked that although the distribution of fire susceptibility is highly dependent on the terrain conditions, the accessibility to the forest products is determined by its availability. In chapter "Understanding the Flood Early Warning System, A Case Study of Transboundary Water Governance in the Gandak River Basin": Shams Tabrez explored the efficacies and information flow regarding Early Warning System for between India and Nepal, in the context of Trans-boundary Water Governance in the Gandak River Basin. His study concluded that political tensions, economic development and power of decision-making have stressed the transboundary issues between the two nations. Attempt to decrease the vulnerability has been given the least importance. In chapter "Adaptation Policy and Community Discourse of Climate Change in the Mountainous Regions of India": Anshu et al. made an attempt to examine if there are consistencies in the adaptation programmes of climate change and community response. But in ground reality, the practical implementation of public policies is thwarted by incoherent and distorted ideologies. In chapter "Analysis of Public Awareness, Health Risks, and Coping Strategies Against Heat Waves in NCT of Delhi, India": Vedika Maheshwari analyzed the public awareness, health risks and coping strategies against heat waves in NCT of Delhi, India through a field survey. Her field survey reported that majority of the respondents considered heat waves as a disaster and extreme heat a serious public health risk. The main issues that concerned the respondents during the heat wave events were health and safety for themselves, families and their pets. In chapter "Community-Based Flood Preparedness: A Case Study of Adayar Watershed, Chennai City, Tamil Nadu, India": O. M. Murali and S. Rani Senthamarai analyzed the community-based flood preparedness in the Adayar watershed, Tamil Nadu, India using transect survey, field survey, participatory mapping techniques and SWOT analysis. The study has revealed varied status and linkages between living conditions of the population, their age structure, income, occupation, environmental stress, prevailing infrastructure and the support they derive from governing bodies. In chapter "Building Resilience and Management of Vulnerability: Solution for Reduction of Risk of Disasters": Nizamuddin Khan and Syed Kausar Shamim made an attempt to scope solutions for risk reduction of disasters by resilience and management of vulnerability. Their study argued that bare religious knowledge and statements are not capable to explain scientifically the genesis and warning of occurrence of hazards and disasters but provide a strong base to the scientists for further exploration. The study is concluded by focusing management of vulnerability as the key for disaster risk reduction management. In chapter "Employability, A Key to Community's Socio-economic Malady of Pandemic Proportions": Ujwal Prakash tried to analyze employability as the key to community's socio-economic malady in the backdrop of the COVID-19 pandemic. His study remarked that enhancing employability by providing employable skills among local workforce will pave a source of income that will reduce the negative impacts of unemployability. In chapter "Living with Floods: Community-Based Coping and Resilience Mechanism of Mising from Floods; A Study of Majuli District of Assam": Bikash Chetry tried to analyze the community-based flood coping and resilience mechanism of the Mising community of Assam, India. He asserted that the community has mastered the practice of traditional healing practices by using herbs and other natural remedy. However, in the modern-day disaster management plans, these knowledgebase couldn't find any suiting place. In chapter "Assessing Public Perception on Developing Colombo Municipal Council Area as a Green City": Rasmiya Niyas and Fareena Ruzaik tried to assess the public perception on designing Colombo municipal council area as a green city. Their field survey reported that majority of the population faces respiratory issues, behavioral changes due to excessive heat. The study is concluded with the limitations that will hinder the conversion of the Colombo into a green city and some suggestions have been made to lighten these obstacles. In chapter "Climate Change and Its Impacts Assessment Through Geospatial Technology-A Theoretical Study from Extreme Weather Perspective for Disasters Resilient India": Niranjan Sahoo used geospatial technology to assess the impact of the climate change, in the aim to build a disaster resilient India. The study claimed that the climate change has direct impact on disasters, and urged to develop an efficient system for monitoring and impact assessment through geospatial technology. In chapter "Corporate Sector and Disaster Risk Management: A Critical Analysis with Reference to Corporate Social Responsibility in India": Vidhi Madaan Chadda and Navjeet Sidhu Kundal to provide a critical analysis of the Corporate Social Responsibility (CSR) in India to implement disaster risk management. The study argues for adoption of a principled approach for devising CSR strategy to mitigate disaster risk, and suggests for policy and legal interventions for facilitating the same. It concludes with a caution that if the recent amendments are enforced effectively may turn out to be instrumental in making CSR regime conducive for disaster risk reduction and building a resilient society. In chapter "Impact of Training and Awareness Programmes of Community Volunteers in Disaster Risk Reduction and Response—A Study of Srinagar City": Bilquees Dar and Sajad Nabi Dar tried to assess the impact of training and awareness programs of community volunteers in disaster risk reduction and response in the Srinagar city, India. The study revealed that after training of the community volunteers, they developed various innovative ways based on their training and inherent skills to reducing the risks and respond to the disasters. The community-based methods of disaster risk reduction and response are very uncommonly scaled out and are not either systematically included in disaster management policies and practices. We thank all the authors who have made valuable contribution to this volume.

Contents

About the Editors

Dr. Haroon Sajjad is a professor and head of the Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India. He received his B.Sc., M.Sc., M.Phil. and Ph.D. degrees all from Aligarh Muslim University, Aligarh, India. His present research interests include climate change/climate variability impacts, environmental management, sustainable development, watershed management and applications of remote sensing and GIS. He has six books to his credit and has published more than 100 research papers in academic journals. Professor Sajjad has presented over 50 research papers at national and international conferences including ones held at Sapienza University of Rome, Italy; University of British Columbia, Canada; University of Western Cape, Bellville, South Africa; and University of Brighton, UK. He has chaired academic sessions at conferences and has organized academic events such as national and international conferences, workshops and training programmes. He has delivered invited talks at numerous universities. Ten doctoral degrees have been awarded to the scholars under his supervision. He is a reviewer for many scientific research journals and a member of scientific bodies and expert panels. He has completed many research projects of various funding agencies as a co-principal investigator. e-mail: hsajjad@jmi.ac.in; haroon.geog@gmail.com

Dr. Lubna Siddiqui is a professor and deputy coordinator, Centre for Disaster Management, Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India. She completed her M.A. at Aligarh Muslim University, Aligarh, and her Ph.D. at Dr. Bhimrao Ambedkar University, Agra, India. She specializes in population geography. Many Ph.D. degrees have been awarded to students under her supervision. She has published more than two dozen research papers in academic journals and presented research papers at national and international conferences; she has been an invited speaker at numerous universities. Dr. Siddiqui has organized many national and international conferences and training programs in her department, and she has completed many research projects of various agencies.

Dr. Atiqur Rahman is a professor in the Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India. He received his Ph.D.

degree from Aligarh Muslim University, Aligarh, India. His research interests include urban environmental management, water resource management and public health. He has published eight books and more than 100 research papers in academic journals. Prof. Rahman has presented more than 50 research papers at national and international conferences including ones held at Arizona State University, USA; McGill University, Montreal, Canada; Brown University, Providence, Rhode Island, USA; and the American Academy of Sciences, Texas, USA. In addition, he has spoken in South Africa, Germany, Italy, France and Poland. Eight doctoral degrees have been awarded to scholars under his supervision. Prof. Rahman has chaired academic sessions at various conferences. He is a reviewer for many research journals and a member of scientific bodies in his field of specialization. He has completed many national and international research projects.

Dr. Mary Tahir is a professor in the Department of Geography, Jamia Millia Islamia, New Delhi, India. She obtained her M.A. degree from Jamia Millia Islamia and her Ph.D. degree from Jawaharlal Nehru University, New Delhi, India. Her research interests include social geography and environmental geography. She is the author of 10 books. Five Ph.D. degrees have been awarded under her supervision. Professor Tahir has published research papers in national and international journals and delivered invited talks at many universities. She has completed numerous research projects and organized national and international conferences.

Dr. Masood Ahsan Siddiqui is a professor and coordinator, Centre for Disaster Management, Department of Geography, Jamia Millia Islamia, New Delhi, India. He obtained his B.A., M.A., M.Phil. and Ph.D. degrees from Aligarh Muslim University, Aligarh, India. His present research fields include the application of remote sensing and GIS in watershed management and waste management. Professor Masood has published four books and some three dozen research papers in academic journals. Fourteen students under his supervision have been awarded Ph.D. degrees. He has completed two major research projects awarded by the Department of Science and Technology and the University Grants Commission. Currently, he is the principal investigator of two major research projects. He has presented many research papers at national and international conferences. As well, he has organized workshops, training programs and conferences.

Hazards: Impact and Assessment

Probabilistic Seismic Hazard Assessment for the Frontal Part of the Mishmi Hills, India and Its Role in Disaster Management

Bijoylakshmi Gogoi, Devojit Bezbaruah, Praghyalakshmi Gogoi, Yadav Krishna Gogoi, Manash Protim Dutta, and Madhurjya Gogoi

Abstract Natural hazards can cause serious disruption to societies and their impact is highly dependent on the resilience of the communities. Normally, earthquakes strike without notice and can be recognized by a variety of direct and indirect impacts, as well as significant damage in a relatively short period of time when compared to other fast occurring natural catastrophes. Seismic hazard assessment is an important tool in any engineering planning, which aims to quantify the estimation of ground shaking hazard of a specific area to mitigate the impact of future disasters. This area is prone to earthquakes on a regular basis, and it was the hardest hit by the earthquake of 1950. Its initial shock measured was of magnitude 8.6, followed by many aftershocks. The purpose of the study is to help the society of the area and to address the vulnerability, mitigate hazards and prepare for response and recovery from hazard events. In the present day study with the help of geographical information system (GIS), the geological maps are processed and the hazard maps are assessed with the help of CRISIS-2007 software. Evaluation of the reliability of the proposed study was performed through uncertainty analysis of the variables used for producing the final output. The findings revealed that the high hazard zones are mainly distributed in the northeastern part of the area under investigation. The preparedness and prevention of an area are very essential for the response and rescue, so the study would be helpful in assessing the seismic hazard of the area so that it would be useful for the

B. Gogoi (✉) · D. Bezbaruah
Department of Applied Geology, Dibrugarh University, Dibrugarh, India
e-mail: bijoylakshmigogoi3@gmail.com

P. Gogoi
Department of Physics, Dibrugarh University, Dibrugarh, India

Y. K. Gogoi
Department of Petroleum Technology, Dibrugarh University, Dibrugarh, India

M. P. Dutta
Department of Geography, NEHU, Shillong, India

M. Gogoi
Coal India Limited, NEC, Margherita, Assam, India

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administration in earthquake hazard management and also use of proper safe standard structures may prevent loss of life and property, especially in the third world countries which are in seismically active zones.

Keywords Seismic hazard · Mishmi Hills · CRISIS-2007

1 Introduction

The tectonic history of the Mishmi Hills is connected to the upliftment of the Naga-Patkai Hills and the eastern Himalayas. The Mishmi Hills are located in the northeast direction of the Upper Assam Shelf and follow the trend of the Himalayas into China (Fig. 1). It has a significant role in the structural evolution of the northeastern region of India. There are several faults and thrust present in the Mishmi Hills (Gururajan and Choudhuri 2003). The Mishmi block is sliced transversely by many thrusts. Active

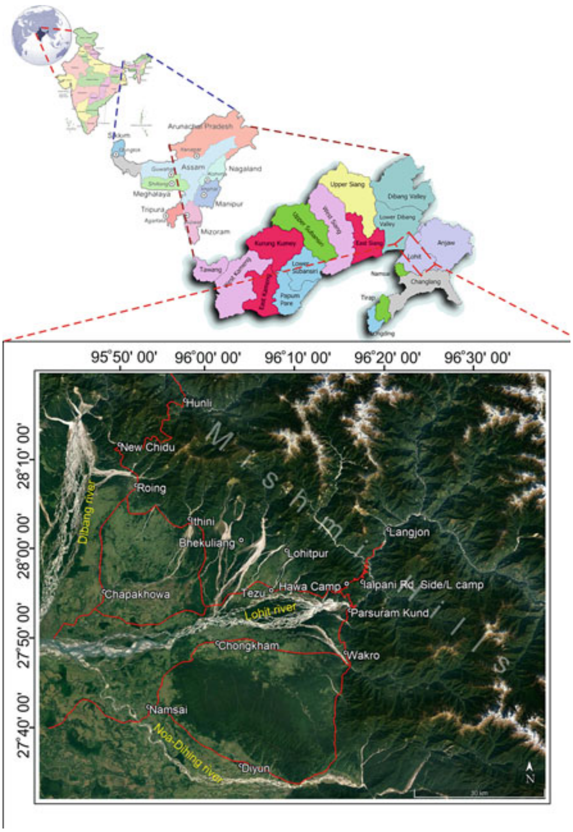

Fig. 1 Location map of the study area

Mishmi thrusts in the Mishmi Hills are discontinuing in nature and are dissected by transverse faults, making them tectonically active (Gogoi and Bezbaruah 2021).

As per the seismological map of the region, the area falls under zone V (BIS, 2004). The area is known to experience disastrous shallow-focus earthquakes (Tiwari 2000). The primary cause of this area's high seismicity is its geological movement, which has resulted in constant uplift resulting in the formation of mountains, hills, valleys and plains. These relative movements occur along deep fractures. Hence, earthquakes occur in this region due to the sudden movement along the faults. In the study area, there have been a few significant earthquake tremors. The Mishmi Hills witnessed one major earthquake, called the 1950 Great Assam Earthquake, which was the largest continental event ever recorded instrumentally (Ben-Menahem et al. 1974; Coudurier-Curveur et al. 2020).

Sadiya, Roing, Tezu and Namsai are towns situated in the frontal part of the Mishmi Hills. They are located in the easternmost part of the northeast Indian states of Assam and Arunachal Pradesh. The construction of Bhupen Hazarika Setu improved the communication between these two states and nowadays fast and unplanned constructions in these border towns are witnessed. The 1950 earthquake damaged a large number of buildings, roads, bridges and railway lines in these aforementioned towns. The earthquake caused abrupt shifts in the levels of the valleys and plains. Furthermore, flooding occurred in the study area due to a 1–2 m increase in river beds.

The area's current geology and tectonics have been identified as a hazard zone, indicating the possibility of significant earthquakes in the future. These towns are situated on both plains and hilly terrains and therefore have to face space constraints for construction purposes. Many towering buildings, including residential and commercial facilities, have been constructed in these towns without sufficient design and seismic analyses. This creates the necessity to assess the status of seismicity in the region realistically. Another major earthquake resembling that of the 1950s if stands it may create great socioeconomic devastation to the region.

Probabilistic Seismic Hazard Assessment (PSHA) parameters such as uncertainties in the earthquake location, its size and rate of recurrence and the variation of ground motion properties with earthquake location and size are considered. As uncertainties can be properly recognized, quantified and accumulated in a rational manner in the PSHA method, it, in turn, provides a better prediction of seismic hazards (Cornell 1968; Algermissen et al. 1982). In this study, the PSHA method has been used to analyse the seismic hazard assessment which is important to minimize the loss of damage to infrastructure and life in seismically unstable regions.

Following the study gap of the region, the objective of the paper is to understand the seismic risk of the entire frontal part of Mishmi Hills with the help of PSHA. And the mitigation measures to minimize the potential loss from future earthquakes are also discussed in this study.

2 Study Area

The Mishmi Hills are situated in northeast India, tectonically separating the Eastern Himalayan and the Indo-Burmese (Myanmar) mobile belts, thus forming a linkage (Nandy 1976). The rivers Noa Dihing, Dibang and Lohit are remarkable in the research region because they are geologically unstable and have high seismicity. Because of the presence of faults in the Mishmi Hills, the geology of the studied region is tectonically unstable. Geologically, the Mishmi block is divided into multiple distinct belts. All these lithotectonic belts are trending in the NW–SE direction and dipping towards NE.

Towards the south-western direction of the Mishmi Hills, the "Mishmi Crystalline is thrusted above the alluvial plains along the Mishmi Thrust. Towards the north direction of the Mishmi Crystalline, the Tidding Formation over thrust the crystalline along the Tidding Thrust and gradually overthrust by rock of Lohit Plutonic complex along the Lohit Thrust" (Misra 2009). The Mishmi Crystalline is divided into two groups of rocks, which include the Lalpani Group predominantly consisting of garnet grade rock and the Sewak Group consisting of greenschist facies metamorphism. The abrupt change of grade of metamorphism was demarcated by the Lalpani Thrust and the Hawa Thrust. "An intra-formational thrust namely Hakan Thrust is present between the Lalpani Thrust and the Hawa Thrust, which falls under the Lalpani group of rocks" (Gogoi and Bezbaruah 2021). Furthermore, between the Lalpani Thrust in the south and the Tidding Thrust in the north, the central crystalline is of high-grade metamorphism of Mayodia Group. Along with the major features, Manabhum Anticline is also witnessed in the region, which comprises the Tipam and Dihing Group of rocks (Fig. 2).

3 Materials and Methods

Field surveys were carried out to gather the information that was used to create the study's geological map. Brunton Compass was used to determine the direction and dip values of the various beds. The geolocation of the stations was obtained using the global positioning system (GPS).

The ArcGIS modelling approach was used to create the earthquake zonation map (Fig. 3). Data from NEIST, USGS and IMD were being used to generate historical earthquake data from 1950 onwards. Since the magnitude scales of the three institutions differ, the data in this research was translated to Mw using mathematical relationships (Scordilis 2006).

The CRISIS software package has been used in this work to calculate the seismic hazard in a given area for the Mishmi Hills. Selection of source and site, the inclusion of source seismicity, spectral ordinates, consideration of current attenuation models and selection of global parameters were the approaches employed step by step for evaluating seismic hazards through CRISIS-2007.

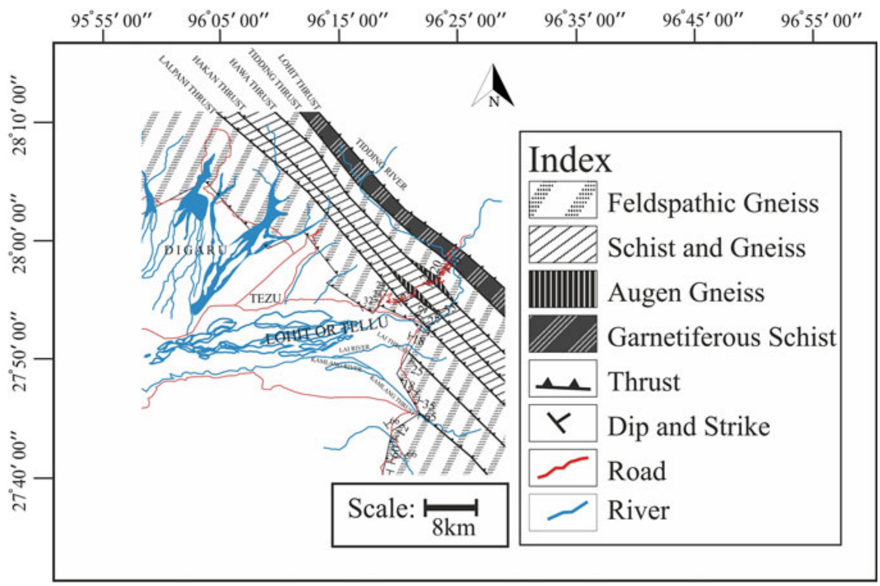

Fig. 2 Geological map of the study area

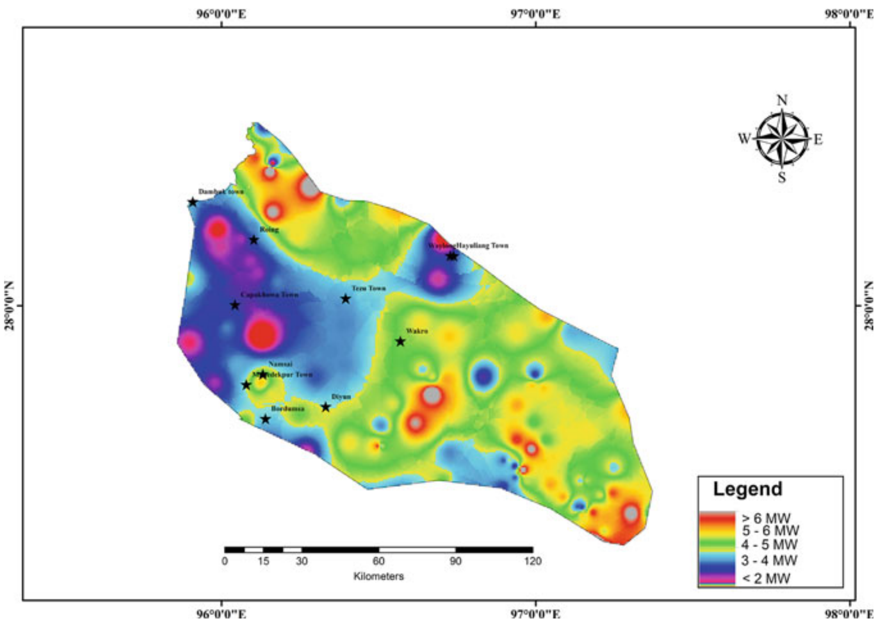

Fig. 3 Earthquake zonation map

4 Analysis

The PSHA for the concerned area estimates the variations in the probability of the exceedance of various parameters within a timeframe for different structural periods. For the study area, the hazard map shows variability in peak ground acceleration (PGA) over a timeframe. Certain structural periods were competed for four different towns, viz., Sadiya, Tezu, Namsai and Roing of the study area. Accordingly, the hazard curves show the probability of exceedance of certain PGA values for the defined structural periods. The input steps in CRISIS-2007 are as follows.

4.1 *Selection of Source and Site*

The study area is divided into grids of 0.165° × 0.165°. Four potential source zones were taken into consideration for the study: the Tulus fault, the Mishmi thrust zone, the Hakan thrust and the Tidding thrust. The zones were digitized using the ArcGIS 10.3, and input was provided to the CRISIS-2007 along with other parameters such as depth and fault mechanism.

4.2 *Inclusion of Source Seismicity*

In CRISIS-2007, the time-independent Poisson's model was used to define source seismicity. In the Poisson's model, while dealing with the shape of the curve for the exceedance rate of earthquake magnitude for a specific return period, parameters such as λo, β, μ and M_0 are extremely important. For all source zones, the seismic pattern was defined and slip rate and slip movement were calculated as shown in Table 1.

4.3 *Spectral Ordinates*

Spectral parameters are defined as the parameterization of a total number of different intensity measures for which hazard is to be calculated. Between the limits of 1 gal (cm/s^2) and 1,000 gal, different levels were chosen, for which the exceedance probabilities were computed. The intensity measures refer to spectral ordinates for different structural periods, which are represented by the rate of exceedance (1/year) versus PGA (gal), for which the hazard scenario is to be estimated.

Table 1 Calculation of slip rate and movement

Parameters	Fault zone			
	Tulus fault	Mishmi thrust zone	Hakan thrust	Tidding thrust
Length (km)	25.31	97.44	168.18	188.95
Depth (km)	20	4	14	22
Threshold earthquake magnitude (M_0)	4	4	4	4
Exceedance rate of earthquake (λ (M_0))	3.8	4.3	4.8	3.1
Expectation of b-value (β)	0.48	0.5	0.4	0.4
Coefficient of variation of b-value E <β>	0.05	0.05	0.06	0.05
Untruncated expected value as the maximum magnitude	6	8.6	8.6	8.6
Untruncated standard deviation of the maximum magnitude	±0.1	±0.1	±0.1	±0.1
Lower limit of the maximum magnitude (M1)	4	6.5	6.5	6.5
Upper limit of the maximum magnitude (M2)	6	8.6	8.6	8.6

4.4 Consideration of Existing Attenuation Models

The CRISIS platform needs a file for specific attenuation law that is to be implemented for calculations while dealing with the attenuation of seismic intensities. For each attenuation characterization of seismic intensities, each file contains the table of values with parameters such as focal depth (in km), magnitude, various measures of intensities corresponding to each magnitude and focal depth, standard deviation of intensity values, period for the corresponding structural seismic intensity and the upper limit of intensity as an optional one. Two types of attenuation models are referred to in the CRISIS platform, viz., user models and built-in models. The user has to define the relationships among size, intensity and focal depth for a particular attenuation pattern in the user model mode. In this study, attenuation models were used to define three source fault models and the Mishmi frontal part model.

4.5 Selection of Global Parameters

For the approximation of earthquake recurrence with specified intensities, the global parameters selection option programme requires specification with certain return periods. Map files were generated for four probable return periods, viz., 100, 200, 400 and 500 years. Other parameters involved are minimum triangle size, the approximate length of the fault and maximum integration distance in km from the site to responsible source geometry. Minimum ratio as the distance/triangle size and distance for M-R disaggregation as a function of magnitude and distance for different intensity levels of exceedance were used. Finally, for hazard calculation execution of the saved data was used.

5 Results and Discussion

In this study, ten structural periods were taken for hazard estimation, which are 0.0, 0.05, 0.10, 0.15, 0.3, 0.5, 1, 2, 3 and 4 s. The frequency of vibration taken along these periods is 0, 20, 10, 6.66, 3.33, 2, 1, 0.5, 0.33 and 0.25 Hz. In this study, the mode of vibration for the associated period 0 s or 0 Hz signified that there are no vibrations in the structure but the ground itself experiences the whole vibration intensity.

5.1 Probability of Exceedance Versus Intensity: Hazard Curve

This study furnished hazard curves indicating the probable rate or probability of occurrence of an event per year, which will generate ground shakes exceeding a specific value in gals (cm/s^2). Parallelly, the specific amount of intensity will exceed at least once for the respective exceedance rate. It also signifies the number of such events that will occur per year. The hazard curves were computed at the centre of four towns (Sadiya, Roing, Tezu and Namsai), using structural periods 0.0, 0.3, 0.05, 0.1, 0.15, 0.5, 1, 2, 3 and 4 s for each of the towns. Figure 4a–d shows the graphs for the four towns.

5.2 Hazard Maps for Different Return Periods

Hazard maps are the representation of the probable hazard scenario of a large area. These maps represent the probable intensity that is likely to be exceeded within a fixed span of the return period. In this study, hazard maps were prepared for 0 s (Fig. 5a–d) and 0.15 s (Fig. 6a–d) for 100, 200, 400 and 500 years. These two specific structural periods were chosen because the period 0 s represents the free ground vibration without any structural motion, whereas the period 0.15 s is found to be associated with the maximum structural acceleration. The hazard maps clearly

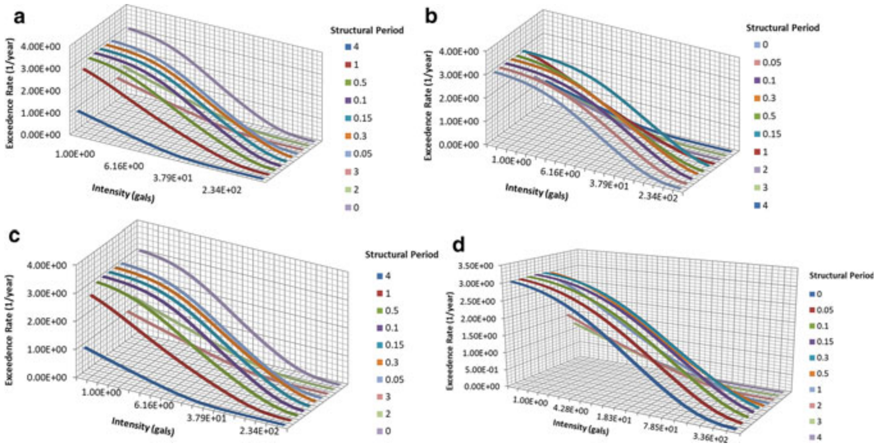

Fig. 4 Probability of exceedance versus intensity (hazard curve)

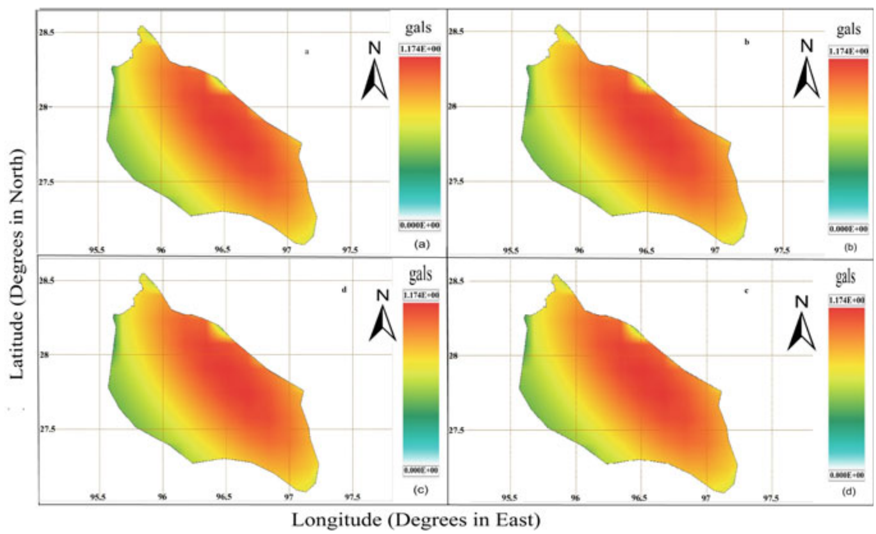

Fig. 5 Hazard map

show that the maximum amount of ground motion is towards the NE direction of the study area.

From the analysis of probabilistic seismic hazard assessment of four locations, viz., Sadiya town, Tezu town, Namsai town and Roing town, it has been observed that the exceedance rate decreases with an increase in intensity in gals for a particular value of the structural period. However, it is also envisaged that the exceedance rate is maximum at a particular value of 0.15 s structural period for the four locations, and it is also clearly highlighted that the probability of exceedance of a certain value

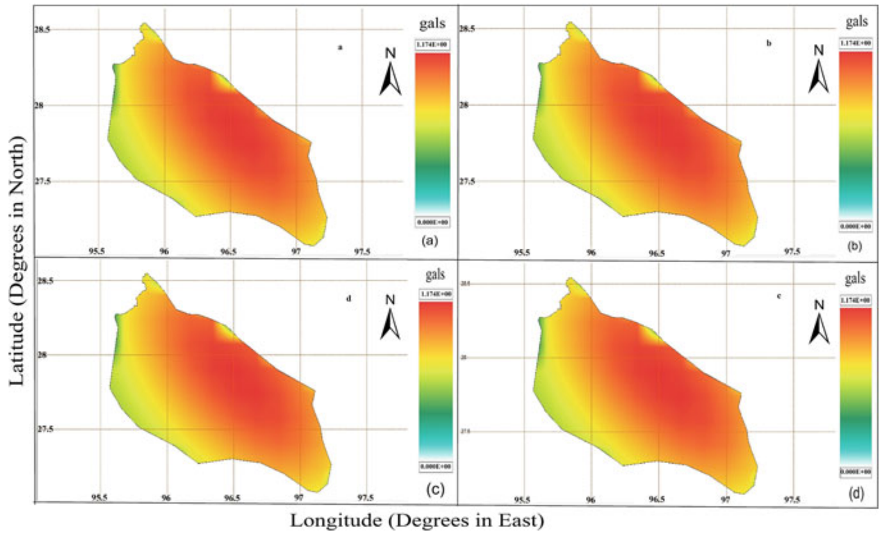

Fig. 6 Hazard map

of intensity is comparatively low for the maximum value of the structural period, i.e., 4 s. Therefore, hazard curves indicating the exceedance rates represent the prior information for a possible scenario, which is likely to occur in a specific time period.

Hazard maps represent that the distribution of probable intensities may exceed within specific return periods of 100, 200, 400 and 500 years for structural periods of 0.0 and 0.15 s. The seismic hazard map of the study region shows that the distribution of intensity (gal) may exceed in a return period of 100, 200, 400 and 500 years for the structural periods of 0.0 s. The seismic hazard assessment suggests that most of the areas towards the NE of the study area are under a higher amount of menace potential to be foisted by the effect of the major thrusts present in the Mishmi Hills.

6 Role of PSHA in Disaster Management

An earthquake is only a natural disaster, which cannot be predicted till now with 100% accuracy. Due to past seismic events and potential hazards from earthquakes, the entire region has been included in the severe seismic zone. The Probabilistic Seismic Hazard Analysis (PSHA) tool is used to reduce and control the hazard. The development of this model can assess the uncertainties in earthquake size, location and time of occurrence. The methodology can be used in any region to carry out the investigation into earthquake prediction, estimate the seismic vulnerability of public and private properties, and may be extended to assess the impact of earthquake mitigation measures.

An increase in haphazard construction has been noticed in the studied towns, which is also considered one of the major factors that increase the vulnerability. The vulnerability study may be given special importance with reference to commercial buildings, hospitals and schools, roads, electric supplies and communication. It is also important to identify safe zones and structures as relief centres in any incidents of future disasters.

7 Conclusion

The study attempts to establish relationships between enhanced seismic vulnerability and natural and anthropogenic activities in the area. Based on historic earthquake data, the area is considered to be seismically active. This study hints that the thrusts present in the area can be the source of high magnitude earthquakes in the future. Such events could manifest aggravated damages since human settlements in the area are rapidly growing without adherence to proper engineering concepts. Therefore, the research concludes that the area is seismically active and there should be diligence in adopting engineering designs for developing infrastructure, which may include commercial or residential properties.

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Assessment of Desertification and Land Degradation Vulnerability in Humid Tropics and Sub-tropical Regions of India Using Remote Sensing and GIS Techniques

S. Kaliraj, Manish Parmar, I. M. Bahuguna, and A. S. Rajawat

Abstract The GIS-based Desertification Vulnerability Index (DVI) model has been used for mapping and assessment of potential vulnerability to desertification and land degradation in the two sites prevailing under different climatic conditions, namely Kasargod district in Kerala (humid tropics) and Virudhunagar district in Tamil Nadu (sub-tropics). The DVI model has executed multivariate statistical indices, namely Climate Index (CI), Soil Index (SI), Vegetation Index (VI), Land Use Index (LUI), and Socio-Economic Index (SEI). These multivariate indices are estimated using multiple geo-environmental and demographical parameters like land use/land cover (LULC), rainfall, soil properties, topography (slope), geomorphic landforms, geological settings, and climatic factors. The Desertification Vulnerability Index (DVI) is calculated using the equation expressed as DVI = $(CI * VI * SI * LUI * SEI)^{1/5}$. The result shows that the Kasargod district in Kerala is not identified with a higher category of desertification vulnerability, and 8.3% of the total area has no significant exposure. The area extend of 91.4% has been found under lower vulnerability conditions, and 0.23% of the area under moderate susceptibility to land degradation in the site-specific areas include Kodakkad, Timiri, Kilalode, Pullur, Panayal, Pallikere, and Bare due to human-induced activities like deforestation and LULC changes. The sub-tropical area of Virudhunagar district in Tamil Nadu shows that 1.4% of the total area has not fallen under land degradation; however, 65.4% of the area falls under low vulnerability and 33.2% under the moderately vulnerable zone. The spatially estimated area of 1428 km^2 (33.2%) is found with moderate vulnerability to desertification. Land degradation in various parts of the district includes Vembakottai, Panaikudi, Narikudi, Sivakasi, Virudhunagar urban proximity, and Aruppukottai, due to severe soil erosion and soil salinization. The 65.42% of the area is noticed as low vulnerability to land degradation; however, the land resources of the various sites are gradually undergoing degradation status due to both natural and anthropogenic activities that become causing adverse impacts on environmental ecosystems. Integrated

S. Kaliraj (✉)
National Centre for Earth Science Studies (NCESS), Ministry of Earth Sciences (MoES), Government of India, Thiruvananthapuram 695011, Kerala, India
e-mail: s.kaliraj@ncess.gov.in

M. Parmar · I. M. Bahuguna · A. S. Rajawat
Space Applications Centre (SAC—ISRO), Ahmedabad 380015, India

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remote sensing and GIS techniques provide an effective platform for sustainable land resources management on a long-term scale.

Keywords Desertification vulnerability index · Land degradation · GIS and remote sensing · Kasaragod and Virudhunagar · South India

1 Introduction

Desertification is one of the significant global issues affecting food productivity; it is caused by the continuous land degradation process in arid, semi-arid, and dry sub-humid landscapes due to climate change and human activities (UNEP 1992; Reynolds et al. 2011; SAC 2021). Desertification that occurs in any region is mainly due to altering the natural settings of biophysical factors that induce land degradation while exceeding the level of their restoration capacity and produce severe impacts on environmental ecosystems and food productivity (Giordano et al. 2003; Wang et al. 2006; Santini et al. 2010; UNCCD 2014; Karamesouti et al. 2015). UNCCD (2014) has reported that about 3.6 billion hectares of the global land surface have already fallen under land degradation, triggering critical impacts like loss of fertile soil and plant nutrients. 25% of the lands worldwide fall under desertification vulnerability due to human-induced factors (UNEP 1992; Ajai et al. 2009; Dasgupta et al. 2013; Kaliraj et al. 2017; Dharumarajan et al. 2018). The semi-arid areas mainly increase land degradation processes compared to other landscapes (Sehgal and Abrol 1994; Singh 2009; Sastry 2011; Kaliraj et al. 2019). Factors influencing land degradation are generally listed as soil erosion, deforestation, encroachment, overexploitation, water-logging, salinization, etc. (Salvati et al. 2009; Giordano et al. 2003; Kaliraj et al. 2014; Jafari and Bakhshandehmehr 2013; Dutta and Chaudhuri 2015; Kaliraj et al. 2015a, b, c; SAC 2016). The process of land degradation is a combined action of biophysical and socio-economic factors that induce irretrievable impacts on their natural settings (Kaliraj et al. 2019; SAC 2021). The increasingly adverse effects on various geo-environmental factors like soil, slope, vegetation cover, and climate directly affect environmental ecosystems and socio-economic conditions (Sastry 2011; Dutta and Chaudhuri 2015).

Nowadays, desertification is one of the severe problems that are directly affecting food production; significantly threatening ecosystems, agriculture, vegetative cover, basic infrastructure, and habitats (Sehgal and Abrol 1994; Kharin et al. 2000; Wang et al. 2006; Frattaruolo et al. 2009; Kaliraj 2016). India is a signatory to the UNCCD and is committed to achieving land degradation at neutral status by 2030. The various government bodies have joined together for combating desertification and land degradation processes in different parts of the country through scientific approaches (Sehgal and Abrol 1994; Ajai et al. 2009; Dasgupta et al. 2013; Dutta and Chaudhuri 2015; Kaliraj et al. 2015a, b, c; SAC 2016; Dharumarajan et al. 2018). In India, the various landscapes have experienced land degradation issues due to human-induced activities that increase adverse impacts on land and water resources.

In India, a total geographical area of about 228 Mha (69%) is noticed under land degradation conditions, especially in the landscapes of arid, semi-arid, and sub-humid regions. It is mainly due to changing natural and anthropogenic factors causing soil infertility, erosion, salinity, and sodicity. Recently, SAC (2021) has published a report on the desertification status of India in collaboration with NCESS and other 12 institutes. The report reveals that 29.77% of the total geographic area is undergoing land degradation during 2018–2019, whereas the major factors inducing desertification/land degradation are water erosion (11.01%), followed by vegetation degradation (9.15%) and wind erosion (5.46%) and the cumulative rate is increased up to 1.87 Mha compared the period of 2003–2005 to 2011–2013. Nowadays, assessment and monitoring of land degradation activities through scientific approaches is vital for sustainable development; hence, the integrated remote sensing and GIS techniques provide an effective platform for mapping the desertification vulnerability by analyzing the multiple geo-environmental parameters (Albaladejo et al. 1998; Wang et al. 2006; Ali and El Baroudy 2008; Dasgupta et al. 2013; Kaliraj et al. 2015a, b, c; Lalitha et al. 2021). GIS-based desertification vulnerability is very much valuable for policymakers in preparing strategic plans for combating these issues. Many studies are executed worldwide for assessing desertification vulnerability using GIS techniques (Frattaruolo et al. 2009; Vu et al. 2014). For mapping, the potentially vulnerable zone to desertification and land degradation, statistical indices are used for analyzing the biophysical and anthropogenic factors at a spatio-temporal scale with the aid of remote sensing images, geospatial tools, and field-based studies. GIS-based desertification vulnerability index (DVI) model is designed to execute multiple geo-environmental variables, i.e., physical (soil quality), environmental (vegetation quality), climatic (climate quality), and social indicators (management quality) for spatio-temporal monitoring and assessment of land degradation status. This study provides a primary data source for the preparation of comprehensive action plans for combating desertification processes. GIS-based DVI model is executed to map potential vulnerability to desertification and land degradation with a minimum cost and better accuracy at a regional and local scale.

2 Description of the Study Area

GIS-based DVI model is used to map desertification vulnerability in two different areas, namely Kasaragod district in Kerala and Virudhunagar district in Tamil Nadu. Figure 1 shows the geographical location of the study area of these two districts. The Kasaragod district covers beautiful landscapes of the coastal stretch of the Arabian Sea and the hill range of the Western Ghats at the northern tip of Kerala. The geographical extent of the area found at the 74°53′21.944"E–75°25′4.1"E longitude and 12°1′42.145″N–12°48′38.53″N latitude and the total area is about 1992 km^2. The landscapes cover the different landforms, including coastal settlements, low-lying wetlands, midland of lateritic plateaus with settlements and plantations, upland hill-range of forest cover, rocky exposure, and rivers with many tributaries.

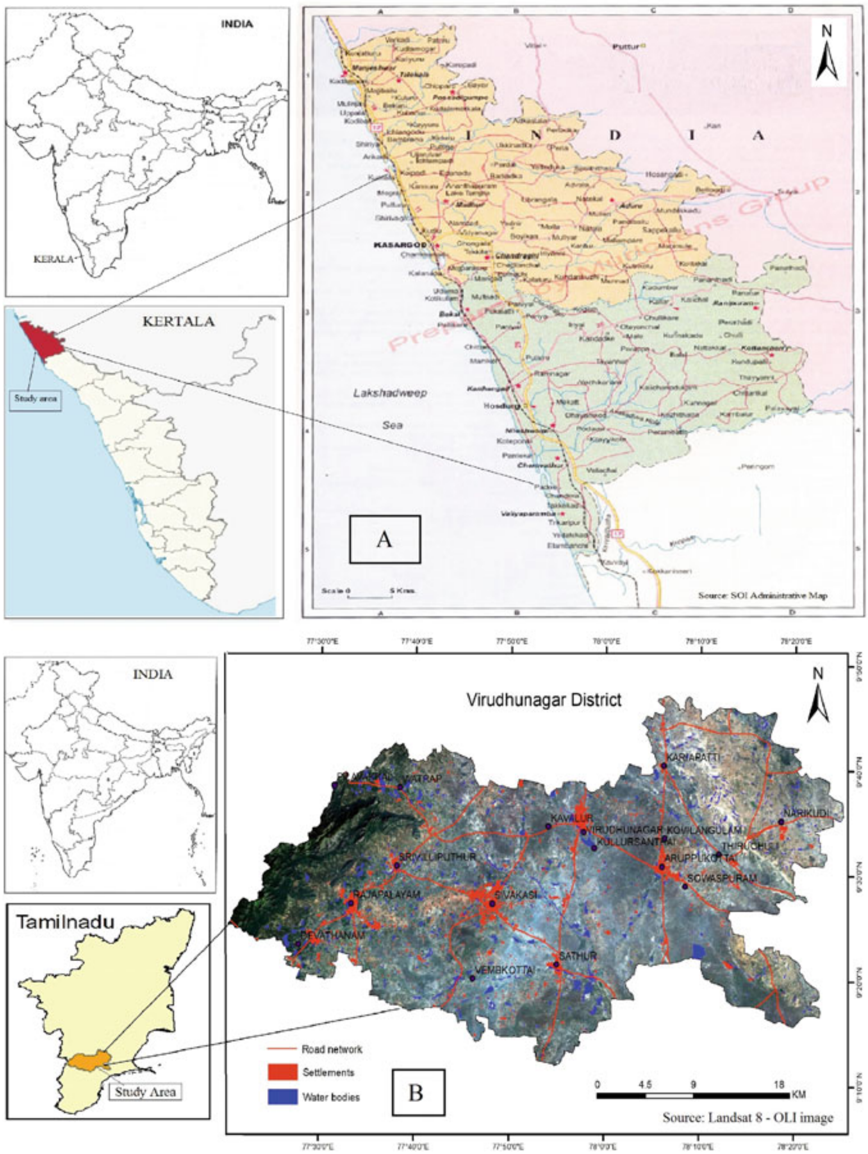

Fig. 1 Methodological workflow of GIS-based DVI modeling for mapping of desertification vulnerability

The tropical climatic conditions are found across the area with an annual average rainfall of 33.50 cm and a temperature range of 17–37 °C. Spatio-temporal distribution of LULC features depends on their landscapes and existing tropical climatic conditions, and it is frequently changing through impacts of natural and human-induced activities. The Virudhunagar district in Tamil Nadu prevails in the sub-tropical climatic condition, which covers the geographical extent of 77°20′26.671″E–78°25′9.097″E longitude and 9°11′5.748″N–9°47′19.758″N latitude. This region covers a total area of about 4232 km^2, whereas the Western Ghats has bounded on the western side, and the rest of the areas comprise the black cotton soils in all directions. This district covers major populated urban areas, namely Aruppukkottai, Kariapatti, Rajapalayam, Sattur, Sivakasi, Srivilliputur, Tiruchuli, and Virudhunagar. Major landforms encompass flood plains, bajada, peneplain, buried pediment, and structural hills in the western parts. In various parts of the district, alluvial plains consist of urban/rural settlements and agricultural lands. In this area, the drainage system encompasses rivers, streams, and water bodies found in non-perennial conditions except during the north-east monsoon, mainly used for dryland agriculture activities.

3 Materials and Methods

Mapping of desertification vulnerability is executed by analyzing multiple geo-environmental parameters using a GIS-based DVI model. Figure 2 shows the methodological workflow of GIS-based DVI modeling used in this study. The DVI model is executed using multivariate statistical indices, namely Climate Index (CI), Soil Index (SI), Vegetation Index (VI), Land Use Index (LUI), and Socio-Economic Index (SEI). Multiple geo-environmental parameters include land use/land cover (LULC), rainfall, soil properties, topography (slope), geomorphic landforms, geological settings, and climatic factors for mapping the vulnerable zone to desertification and land degradation. In this analysis, the CI is calculated using the Global Aridity Index (Global-Aridity_ET0) and Global Reference Evapo-Transpiration (Global-ET0) datasets. In this analysis, the VI is estimated using NDVI products of Landsat ETM + (R/NIR) images in addition to soils, drought resistance, fire risk, and vegetative cover, and it is expressed as VI = (Erosion protection * drought resistance * fire risk * plant cover percentage)$^{1/4}$. SI (also known as Soil Quality Index) is calculated using the equation, and it is expressed as SI = (Soil texture * parent material * slope)$^{1/3}$. The layer of parental material is derived from GSI published lithology map. The slope index is estimated using SRTM DEM (30 m) dataset. LUI is calculated using a Landsat (30 m) ETM + and OLI images-based LULC map; it is derived from a supervised classification technique using the Mahalanobis Distance algorithm. Socio-Economic Index (SEI) is calculated using demographic inputs that include population, unemployment, illiteracy, and poverty rate; and it is noted as SEI = (Population pressure * Unemployment * Illiteracy * Poverty)$^{1/4}$. The Desertification Vulnerability Index (DVI) is calculated using the cumulative value of multivariate indices, and it is expressed as DVI =

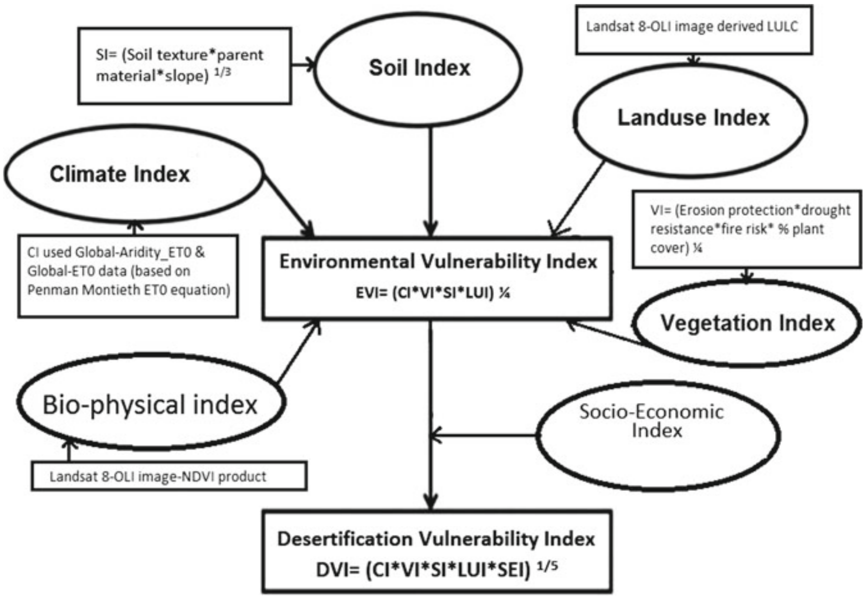

Fig. 2 Methodological workflow of GIS-based DVI modeling for mapping of desertification vulnerability

$(CI * VI * SI * LUI * SEI)^{1/5}$. These multivariate indices include Climate Index (CI), Soil Index (SI), Vegetation Index (VI), Land Use Index (LUI), and Socio-Economic Index (SEI) estimated using multiple geo-environmental and demographical inputs. Integrated remote sensing and GIS techniques are used to prepare these parameters from various data sources at a uniform coordinate system and scale. The GIS tools and functions have been applied to analyze multiple input parameters according to the different statistical indices from mapping the desertification status in the study area.

4 Results and Discussion

Mapping desertification vulnerability is a complex set of processes that incorporate the different statistical indices of multiple parameters affecting land productivity (Ajai et al. 2009; Frattaruolo et al. 2009; Kaliraj et al. (2016); Dharumarajan et al. 2018). In this study, the desertification vulnerability is carried out for two different locations in southern India, namely Kasargod district in Kerala and Virudhunagar district in Tamil Nadu. The GIS-based DVI model is executed to identify potential vulnerability to desertification and land degradation by analyzing multiple geo-environmental parameters. Figure 3 shows the desertification vulnerability map of the two districts of South India: Kasargod (A) and Virudhunagar (B) using the

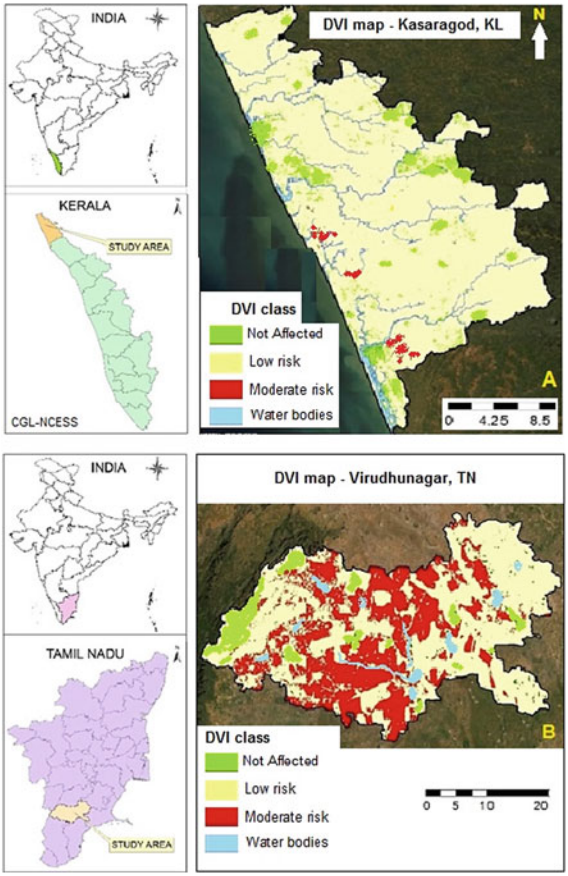

Fig. 3 GIS-based DVI model shows the desertification vulnerability for two districts of South India: Kasargod (**a**) and Virudhunagar (**b**)

GIS-based DVI model. The result shows that the Kasargod district in Kerala is not identified with a higher category of desertification vulnerability, and 8.3% of the total area has no significant exposure. Table 1 shows the estimated rate of desertification vulnerability index (DVI) and its area extend in Kasargod district (Kerala) and Virudhunagar district (Tamil Nadu). Meanwhile, 91.4% of the land was found under low vulnerability and 0.23% under moderate vulnerability to land degradation in site-specific areas, including Kodakkad, Timiri, Kilalode, Pullur, Panayal Pallikere, and Bare due to human-induced activities like deforestation and LULC changes.

In the Kasargod district, the various LULC features are noted as environmentally vulnerable areas due to human-induced activities, which gradually produce significant changes in landscapes and socio-economic conditions. In the Virudhunagar district, many spots face land degradation issues mainly due to severe erosion and soil salinization that adversely impact human society and surrounding environmental ecosystems. Major factors inducing land degradation are caused by various interrelated factors like soil erosion, vegetation degradation, land use change, climate

Table 1 Estimated rate of desertification vulnerability index (DVI) and its area extend in Kasargod district (Kerala) and Virudhunagar district (Tamil Nadu)

DVI rating	Kasargod (KL)		Virudhunagar (TN)		DVI vulnerability class
	Area (km^2)	Percentage	Area (km^2)	Percentage	
100–125	61	1.42	167	8.33	Not affected
126–150	2817	65.42	1834	91.43	Low risk
151–175	1428	33.16	5	0.25	Moderate risk
176–200	NA	NA	NA	NA	High risk

variability, and socio-economic issues, besides the natural and human-induced activities. Impacts of land degradation increased in various parts are drastically decreased crop productivity due to several factors like increasing land surface temperature, soil dryness, morphological deformations, soil erosion, human encroachments, and over-exploitation of water resources.

The Virudhunagar district in Tamil Nadu state has prevailing sub-tropical condition that shows 1.4% has not fallen under land degradation; however, 65.4% of the area falls under low vulnerability and 33.2% under the moderately moderate vulnerable zone. The site is estimated at 1428 km^2 (33.2%) with moderate vulnerability to land degradation in various parts of the landscape that including Vembakottai, Panaikudi, Narikudi Sivakasi, Virudhunagar urban proximity, and Aruppukottai, due to severe soil erosion and soil salinization. The 65.42% of the area is noticed as low vulnerability to land degradation; however, the land resources of the various sites are gradually undergoing degradation status due to both natural and anthropogenic activities that become causing adverse impacts on environmental ecosystems.

Across the Virudhunagar district, the LULC features, especially dryland agriculture, drastically degrade soil fertility and food production due to soil infertility and salinity. In this region, the massive lands are used for dryland agriculture, whereas land degradation is one of the major issues due to soil erosion and soil salinity. In these two districts, the various landscapes fall under desertification and land degradation at different degree levels. It is mainly due to increasing pressure on natural settings that drive erosion, infertility, salinity, etc. For example, removing upland vegetative increases surface runoff (or) overland flow followed by flooding and landslide, eroding topsoil and nutrients from downslope and plan surfaces. The process of land degradation is increasing in various parts due to improper land management practices. The landscapes of those areas accompanied by uplands and rivers/streams are seen as highly productive zones due to prevailing favorable climate and soil conditions. Likewise, the LULC around human-intervening locations is highly sensitive to land degradation due to altering the natural settings of the biophysical and environmental systems.

However, in many areas of these two districts, the agricultural lands are being used for multiple crop cultivation during the northeast and southwest monsoons. It is noted that increasing land degradation silently coupled with impacts of natural and socio-economic factors in these districts may be causing severe effects on the livelihood of the local people.

5 Conclusion

The GIS-based DVI model is used to map potential vulnerability to desertification and land degradation by analyzing the multiple influencing factors at a site-specific scale. The DVI map shows that the various parts of both districts fall under higher vulnerability to land degradation due to increasing adverse impacts that alter regular mechanisms of biophysical and environmental factors. LULC features at various parts are significantly degraded in both districts due to overexploitation of land resources and improper land-use practices. Specifically, in many locations, LULC features around the human-intervening proxy are susceptible to land degradation and desertification due to frequently altering biophysical and environmental systems. However, the massive areas are found with no apparent changes towards land degradation. The increase in land degradation is commonly coupled with impacts of biophysical and socio-economic factors in these districts, causing severe effects on the socio-economic status of local people. It is concluded that the assessment and mapping of desertification vulnerability using integrated remote sensing and GIS techniques provides a primary database for preparing combating plans and sustainable developmental activities.

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Analysis of Diversified Impact of COVID-19 Pandemic Across the Indian States

Alpana Srivastava

Abstract The coronavirus pandemic rapidly spread from China to various countries, and India was no exception. The Ministry of Health and Family Welfare of India initiated the awareness drive immediately after WHO declared it a serious pandemic, and joint mitigation measures were initiated by the central and state governments. A strict 55-day lockdown was imposed by the Indian government which irked the Indian economy but at the same time had a positive effect on the climate. Variation in transmission rate and mortality rate of virus differs significantly across Indian states. Maharashtra was the worst hit, whereas northeastern and hill states fared better. There were fewer cases in rural than in urban India. The strategic steps taken by the Indian government helped in managing the huge population as compared to the western world. On the flip side, poor health infrastructure and manpower, poverty, and unhygienic living conditions posed a big challenge. The present study focuses on bringing out challenges and opportunities faced by the Indian states.

Keywords Pandemic · COVID-19 · Lockdown · Mortality · Challenges · Opportunities

1 Introduction

The first case of the COVID-19 virus was reported from the Wuhan district in China and was assumed to be the case of viral pneumonia. Later in February 2020, World Health Organisation (WHO) declared it a Public Health Emergency of International Concern (PHEIC) when cases surge in different parts of the globe. As it originated from severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), hence named COVID-19. As nothing much was known about the characteristics of the virus, the incubation period in the beginning was 10 days but later increased to 14 days and the disease was highly transmittable. One lakh people were infected in 67 days but infection reached two lakhs just in the next four days showing its exponential growth

A. Srivastava (✉)
Amity Business School, Amity University, Lucknow Campus, Lucknow, India
e-mail: alpana94@gmail.com; asrivastava3@lko.amity.edu

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the world over. COVID-19 was the sixth PHEIC in the last 10 years following H1N1 (2009), polio (2014), Ebola (2014 in West Africa), Zika (2016), and Ebola (2019 in the Democratic Republic of Congo).

The story of the initial stage of the spread of the pandemic in India was distinct from the rest of the world. Being the second most populated country with 70% of them living in the rural areas, it announced the strict lockdown on 24 March 2020 when there were a total of 562 cases (Srivastava and Srivastava 2020). The reason was its high population with low health infrastructure, high poverty, less literacy, etc. to fight the deadly disease. This gave time for preparedness and delayed the peak. India also imposed the quarantine law under the Epidemic Disease Act, of 1897 to make the lockdown and social distancing effective. This 123-year-old legislation authorises a state/country to examine people travelling by railways or ships (air travel was introduced later), and send suspects to the hospitals, any temporary accommodations, or any other isolated place to prevent the spread of disease.

Daily cases peak reached over 90,000 cases per day during mid-September 2020 and dropped to less than 15,000 per day in January 2021. The delayed peak during the first wave and smaller death rate brought laxity in covid management on part of both citizens and government. The second wave of the pandemic began in March 2021 in India and the intensity of infection was very high. Neither government nor the public was ready to face the sudden surge in cases.

Health infrastructure was not adequate to cope with the rising emergency. All over the nation, there was a shortage of vaccines, hospital beds, oxygen cylinders, medicine, etc. On 30 April, India became the first nation to report 400,000 new cases per day and experts were of the view that these figures may still be under-reported due to several factors like partial lockdown, festival, election, Kumbh, and breaking up of COVID-19 protocol by common people. The sudden steep spike in the second wave is shown in Fig. 1.

India started its vaccination programme on 16 January 2021 with two main vaccines, viz., first Covishield (a local version of the Oxford-AstraZeneca vaccine) developed by Serum Institute of India (SII) and second Covaxin (an indigenously

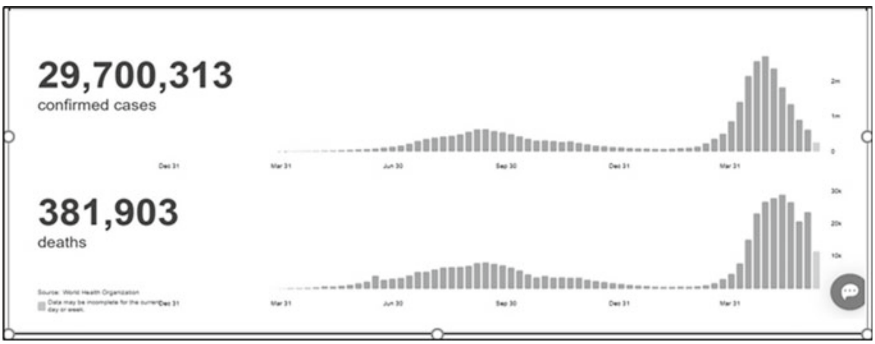

Fig. 1 Two waves of COVID-19 cases in India

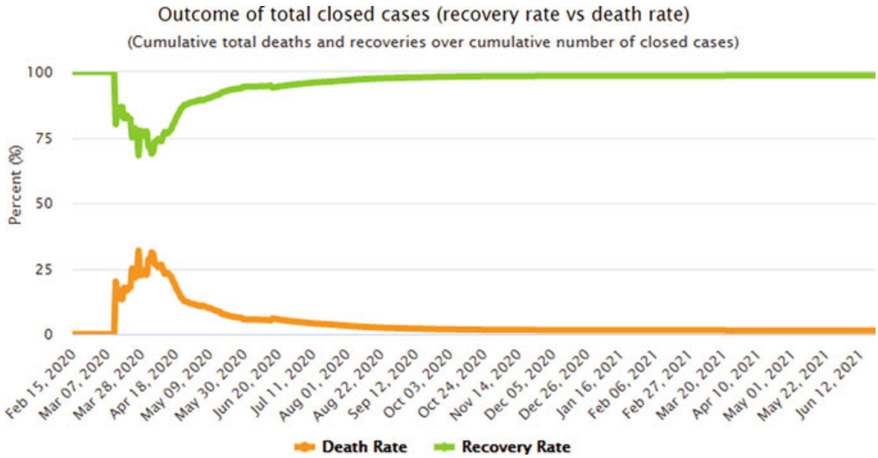

Fig. 2 Recovery rate versus death rate

developed vaccine) developed by Bharat Biotech. Later on, the Russian Sputnik V vaccine was also allowed for emergency use. By 12 October 2021, India has administered over 958 million doses (first and second both), covering nearly 60% of its huge population.

As the vaccination drive was slow and applicable for 50 plus age group, the second wave drastically hit the younger population who were out for a job. Though the experts were warning of the second wave, the authorities were not equipped for the second wave which came unexpectedly. The wave was high because there was no lockdown and neither common person was obeying COVID protocol. To add to the woes, the second wave was more serious than the first because cases increased exponentially whereas infrastructure was poor and could not cater for the rising number of patients. Moreover, this time doctors and paramedical staff were affected on a larger scale than before even after taking at least one dose (though mortality was low) and this affected the overall healthcare system. Mutation of viruses is always a concerning phenomenon, and so was the case with SARS-CoV-2, which is mutating at a rate of about 1–2 mutations per month [1]. A new double mutant strain of coronavirus found in India was having high spreading rate. The multiple factors responsible for the sudden surge in cases during the second wave resulted in high mortality numbers but the mortality rate was not very high as seen in Fig. 2.

2 State-Wise COVID-19 Situations in India

As India is a large country with a diversified environment and culture, hence regional disparity plays a pivotal role in studying any phenomenon in India. The total picture of COVID management could not be true if the state-wise analysis is not done.

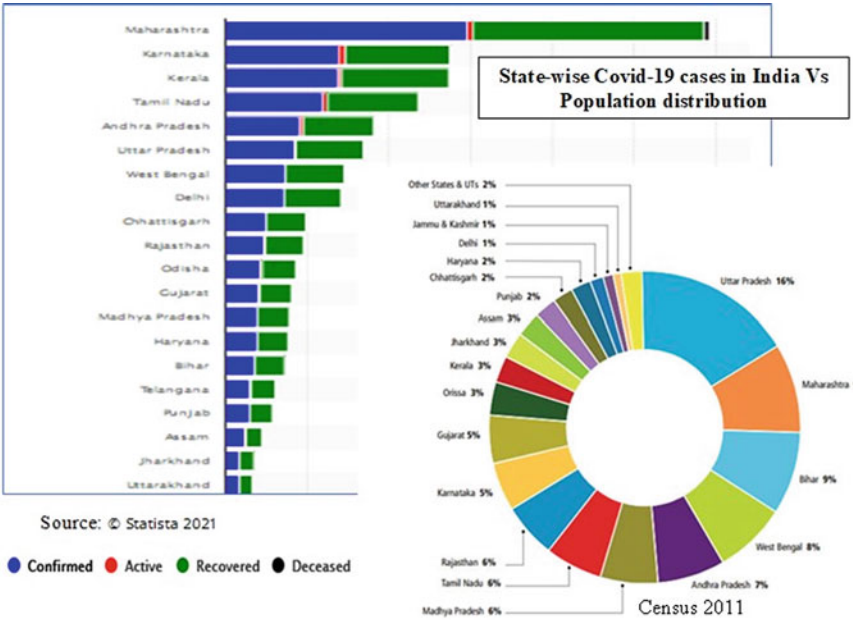

Fig. 3 State-wise distribution of COVID cases and population distribution

Each state varies in population, population density, geophysical characteristics, food habits, culture, literacy rate, infrastructure, and many more uncited factors. Figure 3 shows the total number of cases in the state along with the pie chart depicting the population of states.

Instantly, it could be seen that Maharashtra was the biggest hit state having the second-largest population (2021 census) at around 11.2 crores and a population density of 365/km^2 (950/m^2), whereas with a nearly similar population and higher population density (10.4 crores, 1,102/km^2 (2,850/m^2) Bihar was not much affected. Infrastructure-wise, literacy-wise, and many well-being indicators of Maharashtra are better than in Bihar, so more research is needed to explore the exact reason for the uneven spread of the COVID virus in these states. The situation of COVID-19 was alarming in the state of Uttar Pradesh with the highest population of 19.9 crores (census 2021), but much better than Maharashtra, Kerala, Karnataka, and Tamil Naidu. Kerala, the most advanced state of India, is fairing high in development index, with a population of only 3.3 crores and population density of 859/km^2 (2,220/m^2) was the third largest hit state in India. Another small state and India's capital Delhi was hit high during both the waves of COVID-19.

With this background, this paper tries to explore the issues and challenges faced by the various states in coping with the recent pandemic. Also, this article is a review article, hence statistical analysis could not be done to see the effect of various cited parameters.

3 Methodology

The descriptive research design is applied in this article. The secondary data were collected and analysed from sources like the WHO dashboard and the Indian government's official release. The SWOT analysis tool is used for understating the diversified impact on various states of India. SWOT analysis becomes important when at the policy level we have to assess our strengths and weakness for taking strategic decisions within the constraints of the internal and external environment. It also helps in critically analysing the opportunity emerging and treats to be faced by the decision-maker. Thus, this is a helpful tool for making critical strategic decisions (Fig. 4).

Strength and weaknesses are internal and can be managed within the system concern, whereas opportunity and threats are external, and we can only react to this. SWOTs analysis is done to improve plans for achieving goals.

The findings of SWOT analysis will help the planners, policymakers, etc. to identify the gaps in planning the pandemic related policy announcement and their implementations. Assessing infrastructure status demand and supply gaps and filling them with indigenous technological innovations or collaborations or coming up entirely with new initiatives. This helps in finding new opportunities and working on eliminating or minimising threats. As a strategic analytical tool, SWOT analysis has some weaknesses too. Firstly, it is a theoretical approach based on individual outlook, hence is subjective in nature. Touches too many factors irrespective of their importance, hence sometimes fails to give focused information.

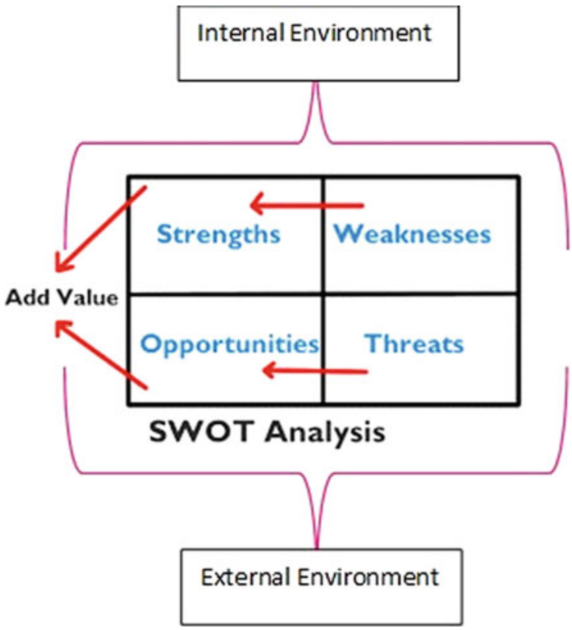

Fig. 4 SWOT analysis flowchart

4 Critical Analysis

As we have seen in the above discussion that there was variation state-wise, hence management also differed. This article now will critically analyse the factors responsible for the diversified impact of COVID-19 in India through the SWOT analysis tool.

4.1 Strength

- Low incidence of disease was seen mainly in most populated states (UP, Bihar, MP, Rajasthan, and WB) with only Maharashtra as an exception. Delhi and Kerala were the states where the population affected was around 8%. Maharashtra and Karnataka states were having cases below 5%. The most populated Uttar Pradesh state reported only 0.75% of the population that got affected. Hence compared to the global prevalence rate, India was in a much better position (under-reporting could not be ruled out). This is shown by the graph in Fig. 5.
- Strict lockdown in the first wave helped in disease spread, along with it also created awareness among common people for following the COVID-19 protocol. It also delayed peak and health infrastructure could be increased. The second wave was sudden and drastic compared to the first, but still with the help of partial lockdown the prevalence of covid cases was low.

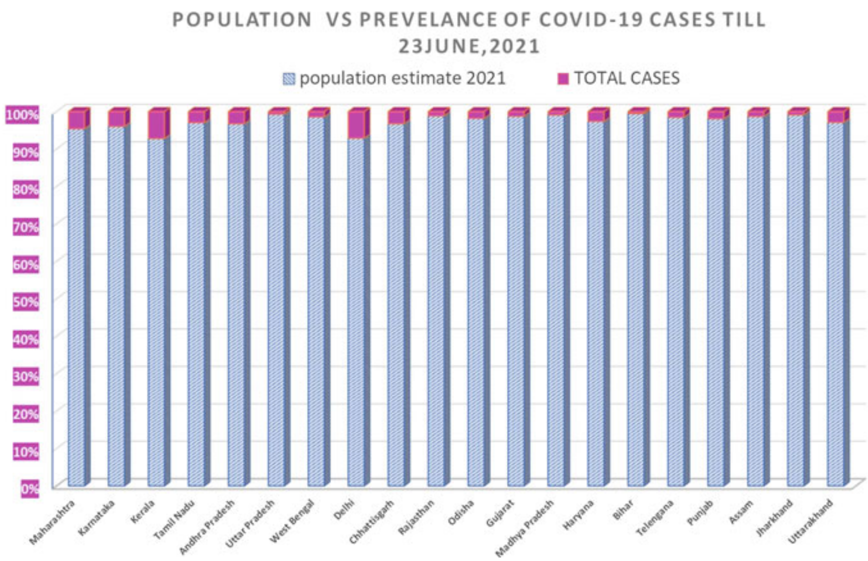

Fig. 5 Population versus prevalence of COVID-19 cases in Indian states

- Health screenings at the airports and sealing the border between states helped in preventing the spread.
- During the second wave, state-wise mitigation measures helped in keeping the economy in momentum.
- On 16 January India began its vaccination programme, the largest in the world, and seeing the surge it amplified its programme by stopping the export and increasing the supply to meet domestic demand. States with a higher population like UP and Maharashtra have administered more doses. The distribution till 19 June 2021 is given in Fig. 6.
- Vaccination trials for kids were given the nod so that even they could be vaccinated soon and could be saved from future waves.
- Antigen and RT-PCR sample tests were increased to a large extent in a few states to check the spread. Massive checking of infected persons or suspected or having any travel history was done at the government's end to check the community transmission.
- Several committees, NGOs, advisory groups, empowered groups, and taskforces came forward in response to India's COVID-19 mitigation measures. Some of

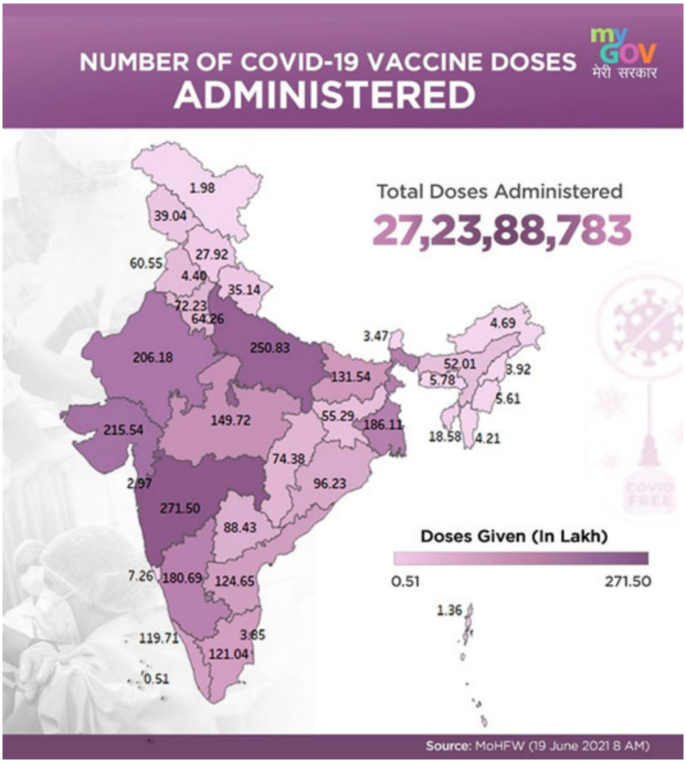

Fig. 6 GIS map of vaccination in India

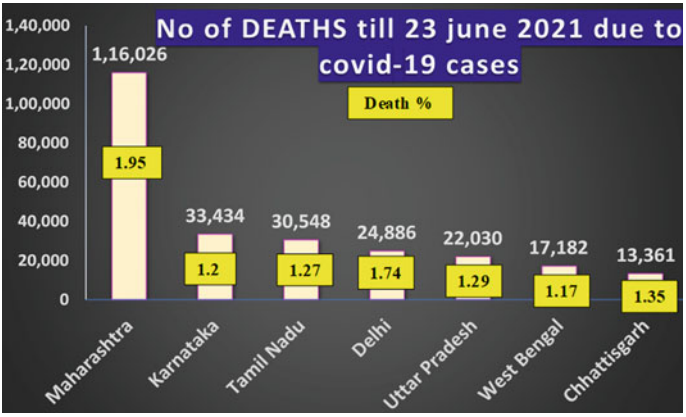

Fig. 7 Deaths due to COVID-19 till 23 June 2021

these were constituted following the onset of the pandemic such as the ICMR COVID-19 Task Force, the National Expert Group on Vaccine Administration for COVID-19 (NEGVAC), formed in August 2020, etc. to help the government on every front. The Prime Minister and his office keep an eye on all responses.

- The Indian government was supported by the Indian military during the pandemic. In the second wave, some of the steps taken by the Indian military to help the health sector in the crisis moment by setting up COVID facilities, oxygen PSA plants, providing domestic and international air and water transport assistance, providing medical assistance to civilians, providing nursing assistance, and roping in retired military medics.
- The overall death rate in India was below the global average. The states reporting a higher number of cases and deaths also had a lower death rate. The states like Kerala reported the second-highest COVID-19 cases, but the death rate was only 0.42%. Good health infrastructure and complete literacy may be the reason behind reduced mortality. State-wise variation of the number of deaths and death rate is given in the graph in Fig. 7.

4.2 Weakness

- Inadequate health infrastructure in highly populated states and rural areas was the main reason for high mortality during the second wave (Fig. 8).
- Oxygen, lack of hospital beds, and the drug shortage were the major problems in most of the states in India like UP, Bihar, and Delhi during the second wave. The shortage was more of the mismanagement in various states and cities rather than the actual supply mechanism.
- Undercounting of cases and fatality was reported mostly by most states, viz., West Bengal, Delhi, Tamil Nadu, Maharashtra, Madhya Pradesh, Gujarat, Telangana,

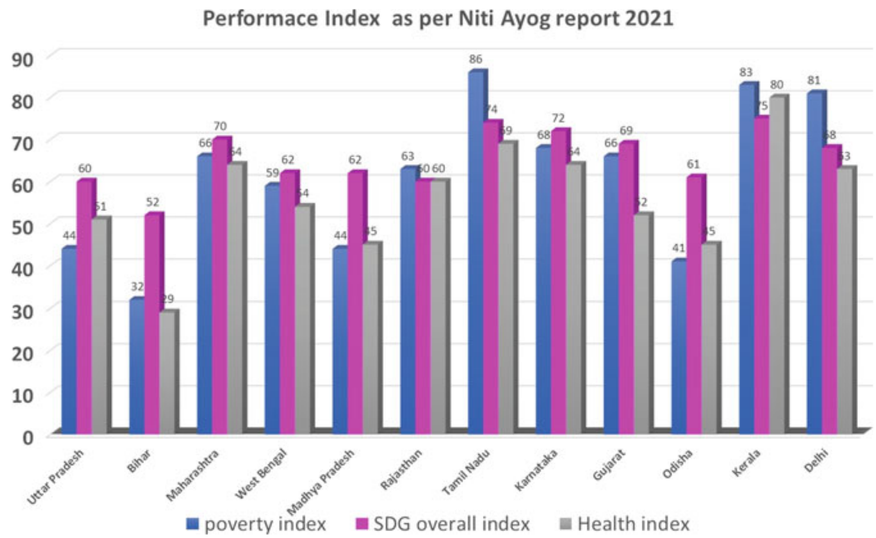

Fig. 8 Niti Ayog performance index 2021

Uttar Pradesh, Assam, Odisha, Kerala, Karnataka, Bihar, Haryana, and Chhattisgarh. These states cater to almost 80% of India's population. The second reason for under-reporting was the low awareness level in rural India and slumps of urban regions. One of the national media reported that rural Uttar Pradesh has been hit catastrophically during the second wave.

- Lack of COVID-19 testing kits and inefficient hospital management in testing and giving the RT-PCR report of the patient created chaos in the state of UP, Delhi, and some other northern states. The situation was better in Maharashtra, Kerala, etc. There was also a shortage of medical equipment, PPE kits, hospital beds (hospital beds to people ratio: 0.7:1000), and ventilators (ventilators to population ratio 40000:1.3 bn). Doctors (doctor to patient ratio: 1:1445) and paramedical staff was also suffering from COVID-19, thus accelerating the shortage.
- After the ease of the first wave, people started social gatherings and a lot of the movement which also accelerated the surge in COVID cases. More international movements from Maharashtra, Gujarat, Tamil Nadu, Karnataka, and Kerala were the reasons for the delta variant spread. On the other hand, election was the major spreader in UP and Kumbh in Uttarakhand.

4.3 Opportunity

- Migrant workers are mostly from the Bihar and UP regions, where sugar, jute, silk, and clothes industries were stopped because of high headedness of Congress, SP, JDU, and BJP leadership in the states. Corona lockdown should be taken as a God-sent opportunity for setting up industries in Bihar and the UP regions or reviving those lockdown units in Gorakhpur, Kanpur, or Mithalanchal areas. COVID-19 really brought an opportunity to regularise these unorganised sectors. This gives the opportunity to create the central commission for migrant labourers and state commissions. This will lead India to all-around prosperity and growth in the future.

- Pandemic was the biggest time to grow for the pharmaceutical and IT sectors. All other sectors showed a declining trend. Essential items maintained stagnant growth. From auto-driver to e-rickshaw drivers, all daily-wage labourers started selling vegetables door to door.
- Overhauling of the health sector was done by appointing more paramedical staff for COVID care, hence employment increased in this sector.
- Boost for the health insurance industry as more and more people started buying these plans. Maharashtra leads followed by Delhi, Karnataka, West Bengal, Tamil Nadu, UP, and Gujarat, to name a few.
- Digital India got an automatic boost during the pandemic as e-payments and online shopping saw a new height. Global data shows India's inclination towards more grooming digital future in the post-pandemic world. Demand for skilled technical job roles like an application developer, lead consultant, salesforce developer, and site reliability engineer grew to a new height of 150–300% during one year of the pandemic.
- Agriculture was the only sector that registered growth during the lockdown [39]. In the agriculture subsector, some states have witnessed a decline in production like Chhattisgarh (13%) and Himachal Pradesh (15%), whereas some large states like Telangana (23% increase), Punjab (5%), Rajasthan (4.4%), and Gujarat (6.7%). States like UP and Maharashtra reported no change.
- Lockdown drastically improved air and water quality in India. The levels of particulate matter PM10 and PM2.5 were reduced by half, for one. This was achieved at the cost of economic growth. Thus in near future to main environmental balance and also to give a boost to the economy, some tuff measures need to be taken from the government end.

4.4 Threats

- As most of the workforce is in the informal sector (90%), the sudden announcement of the lockdown without any alternate arrangements for migratory labour created the biggest chaos across India. Labours from Delhi and Maharashtra started going back to their native states like Uttar Pradesh, Bihar, and Odisha on foot. This was considered the biggest threat to the state government.
- Maharashtra, the largest onion trading market in Asia, went into panic mode as no drivers or workers were available to transport it. Similarly, the northern state of Haryana and Punjab have to throw an abundant harvest of cucumbers and bell peppers due to a lack of workers. Karnataka, the largest coffee-producing state in

India, was unable to sell coffee as there were no traders and workers to support the trade.

- Due to growing globalisation, few states reported a high number of cases as international migration in these cities was also very large. Delhi, Mumbai, Chennai, Cochin, Bangalore, Hyderabad, Calicut, Trivandrum, Kolkata, Ahmedabad, and Trichy were the few cities with 90% of the international migration of the Indian workforce [13].
- High population density, religious beliefs, festivals, etc. also played a pivotal role in spreading communicable diseases.
- Lockdown impacted the education system adversely in almost all the states in India.
- The biggest threat was to the hospitality industry and tourism as few states were dependent on tourism for their livelihood only like Sikkim, Uttarakhand, Himanchal, etc.
- Livelihood threat was majorly for manufacturing and construction sector as they were labour-intensive. The migration of labour stopped production and distorted the supply chain.
- States' revenue from goods and services tax as well as value-added taxes have fallen more sharply than anticipated in FY21 budgets.
- Unemployment reached its peak since independence during the lockdown. Recently, though it has shown an increasing trend, it is still around 18% (very high). The first quarter of the financial year 2020 was very badly hit as the GDP declined 23%. The economy was at crossroads (Fig. 9).

4.5 Internal and External Environment

India's IT penetration in most of the interior areas helped a lot during the pandemic. The energies of front-line warriors like doctors, nurses, and other common people who came out to render help became counties biggest resource during the pandemic. The army and air force strengthen the fight against the pandemic by helping civilians on all fronts. Macro, as well as micro plans, were initiated by mobile phones. The Aadhaar-led unique identification system of citizens helped in coordinating vaccination programmes, drug delivery, and tracing cases (RT-PCR needs Aadhaar registration). The power of IT in education, business and running offices offline, etc. made India self-sustainable. Agriculture was the sector which helped India to feed its huge population even during a harsh lockdown. Our strength and capability of turning threats into opportunities during the pandemic enhanced our internal as well as external environment.

At one point in time media played a positive role by spreading awareness to the common mass but later the unreported cases and other grim pictures were hidden from the citizen showing a negative face of the media and government. The mismanagement during the second wave was taken seriously by the government and common people which brought the situation into control with lockdown 2. The economy

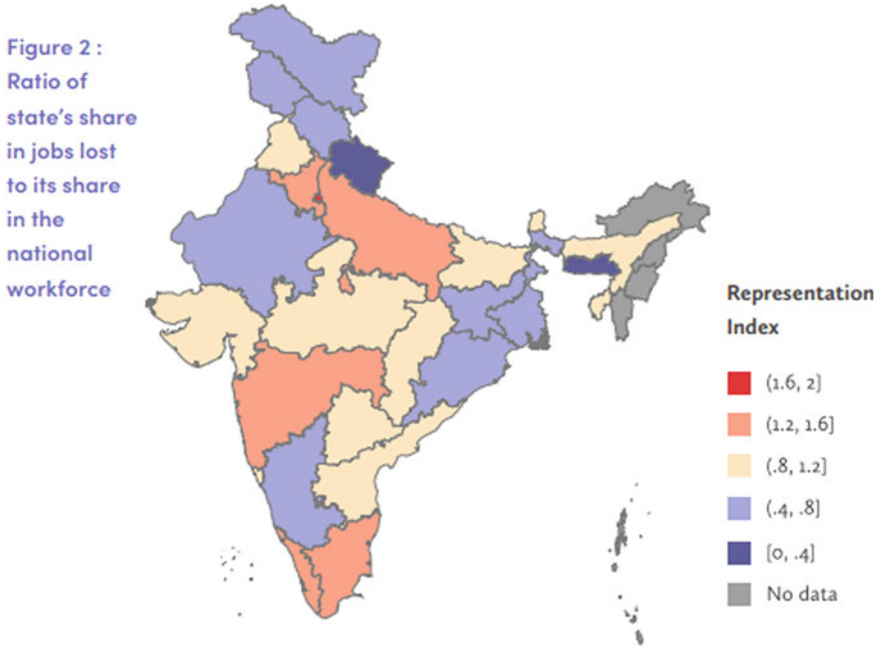

Fig. 9 State share in jobs during 2021 in India

started showing recovery and India became self-sufficient in a few pharmaceutical products and instruments. Make in India got a good boost during the pandemic. Freebies were given to the BPL population during the lockdown and even after it helped them to sustain their livelihood. Though India faced a roller coaster ride during the pandemic in various policy implementations, still the efforts of the common people and government placed India in a much better place than Europe and America. Pandemic is the learning for all.

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Sunusi B, Adamu U, Kumar A, Barik M, Challenges for COVID-19, SARS-CoV-2, influenza, HIN1 development of vaccine and way forward

Spatio-temporal Analysis of Seasonal Drought Pattern Using Vegetation Condition Index in Latur District

Shahfahad, Mohd Waseem Naikoo, Ishita Afreen Ahmad, Swapan Talukdar, Mohd Rihan, and Atiqur Rahman

Abstract Draughts have become increasingly common in India's western semi-arid region in recent decades. Therefore, the purpose of this study is to investigate draught patterns in the Latur District of Maharashtra, India, using the normalized difference vegetative index (NDVI) and vegetation conditions index (VCI) derived from Landsat data sets. The research was conducted during the pre- and post-monsoon seasons of 1996, 2002, 2009, and 2016. The mean NDVI values show a significant decrease during the study period in both pre- and post-monsoon seasons. The study area was divided into seven categories based on VCI values, i.e., no drought, low drought, moderate drought, high drought, very high drought, severe drought, and water bodies. According to the VCI results, the maximum area was under high drought (3326 km^2) in 1996, followed by very high drought (2140 km^2) and moderate drought (994 km^2) in 2016, and the maximum area was under very high drought (3964 km^2) in 2016. (2682 km^2). During the post-monsoon season, the maximum area was under high drought (3010 km^2), followed by moderate drought (1884 km^2), and very high drought (1269 km^2), whereas during the pre-monsoon season, the maximum area was under very high drought (3964 km^2), followed by high drought (1884 km^2), and very high drought (1269 km^2) (2682 km^2). The findings of this study can help in the drought management and planning in the study area.

Keywords Seasonal drought pattern · Vegetation condition index · Normalized difference vegetation index · Landsat datasets · Latur District

1 Introduction

Drought is a recurring climatic event characterized by inconsistency in rainfall and long durations that occurs in many dry and semi-arid regions around the world (Tian et al. 2020). Drought is a multidisciplinary concept that can be meteorological, agricultural, socioeconomical, or hydrological in nature (Zarei et al. 2021). It starts

Shahfahad · M. W. Naikoo · I. A. Ahmad · S. Talukdar · M. Rihan · A. Rahman (✉)
Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi 110025, India
e-mail: arahman2@jmi.ac.in

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with a lack of rainfall, which stresses soil moisture contents and causes high land surface temperatures, affecting vegetation development (Kim et al. 2021; Dikshit et al. 2020; Stojanovic et al. 2020). In order to fully comprehend the phenomenon of drought, as well as to monitor and predict it, the variables of precipitation, soil, and vegetation and their interconnected factors, must be thoroughly studied (Cartwright et al. 2020). Furthermore, drought can occur as a disaster in every climatic regime around the world on a year-to-year basis, and it is harmful to the ecosystem and human activity (Trenberth et al. 2014).

Drought has a wide range of effects on human lives, including agriculture and the economy. Along with having an influence on a region's food security, drought has a negative impact on commercial crops, reducing farm earnings (Mishra et al. 2021). Drought causes decreased livestock weight, decreased livestock productivity, lower reproduction, and increased disease susceptibility in livestock (Dzavo et al. 2019). During droughts, the growth cycle of pastureland plants shortens, reducing the length of the grazing season (Ding et al. 2020). Droughts can cause fires in forests and rangelands, which can be economically damaging and permanent, as well as environmentally devastating. Furthermore, because of the fire's devastations and reduction of vegetation density, the run-off coefficient and soil erosion have increased which has a significant impact on the frequency of floodwater and sediment transfer to dam reservoirs. (Areffian et al. 2021). During a drought, increasing water temperature encourages algal growth, which reduces dissolved oxygen and water toxicity, impacting both aquatic organisms and humans. (Mishra et al. 2020).

Numerous studies have been conducted for the assessment of drought conditions in India. Drought studies in India are mainly based on data from historical meteorological stations. Drought has a negative impact on the economies of countries such as India since the majority of people rely on agricultural revenue, and affects approximately 50 million people each year (Singh et al. 2020; Pathak and Dodamani et al. 2020; Sharma and Goyal 2020; Ramkar and Yadav 2018). It is common throughout the country's subtropical, arid, and semi-arid areas, particularly in the western and peninsular regions. Drought causes a scarcity of water, leaving major areas unusable for farming all year. This has a negative impact on both human lives and livelihoods, as well as on animals (Yazdani et al. 2021; Sun and Zhou 2020).

Monitoring is a critical part of comprehensive drought management. Drought management necessitates both analytics and risk assessment in which forecasting is an essential component (Arabameri et al. 2021; Baniya et al. 2019). There are two types of drought monitoring indicators: indicators based on meteorological observation and remote sensing monitoring indicators. The standardized precipitation index (SPI) (Mahmoudi et al. 2021; Dutta et al. 2013), crop moisture index (CMI) (Mohammed et al. 2020), Palmer drought severity index (PDSI) (Altunkaynak and Jalilzadnezamabad 2021), and others are among the meteorological observation indicators. These indicators are based on ground-based observation stations' hydrological and meteorological data, such as runoff, precipitation, temperature, and soil moisture. Interpolation computations are required to achieve spatially continuous monitoring in the use of meteorological observation indicators since ground observations are based on point data. As a result, because the number of stations is restricted and the distribution is unequal, the drought monitoring data are highly questionable (Khosravi et al. 2017).

Remote sensing monitoring indicators are derived mostly from remote sensing data, such as the normalized difference vegetation index (NDVI) (Nanzad et al. 2019), temperature vegetation drought index (TVDI) (Wang et al. 2020), and vegetation condition index (VCI) (Mishra et al. 2020), among others. The NDVI is a simple measurement that can be used for longer time periods than the TVDI. While utilizing the NDVI to identify drought in various places, it is challenging to get optimal results because of its sensitivity to the geographical context. Kogan (1995b) developed the VCI index, which is based on the NDVI, to address these issues. The VCI can reflect severe weather variations, minimize spatial NDVI fluctuations, reduce the effect of weather, soil, vegetation type, and terrain as well as compare various locations. (Bhaga et al. 2020). As a result, the VCI has become a popular tool for drought monitoring and analysis.

In northern China, Liang et al. (2021) looked into the possibilities of utilizing the VCI for drought monitoring and found that it can correctly represent the geographical distribution and change in drought. Vanajith et al. (2021) employed VCI anomalies as indicators to study the onset and progression of drought in the Solapur district of Maharashtra, demonstrating that the VCI may be used to track drought situations in a variety of situations. Also, Singh et al. (2021) used VCI anomalies to detect changes in vegetation due to drought and compared them to historical values from previous years in the same time period in the drought-prone district of Sangli, Maharashtra. These studies have focused on the status of drought in a certain region, but they didn't look at the situation of seasonal droughts in any of the study areas in India. Therefore, the current study employs the vegetation condition index (VCI) to examine the spatio-temporal situation of seasonal drought in the Latur district of Maharashtra from 1996 to 2016 using long-term remote sensing data. Given the significant impact of seasonal drought in various drought-prone parts of Maharashtra, it is very important to conduct disaster prevention and mitigation research utilizing long-time series seasonal VCI data to study the spatio-temporal variation pattern of seasonal drought.

2 Research Methodology

2.1 Study Area

Drought is a serious issue in the drought-prone areas of Maharashtra State, where agriculture is the primary source of revenue. Latur is one of Maharashtra's drought-prone districts. It is located on the border of Maharashtra and Karnataka to the south-east of the state of Maharashtra. According to the 2011 census, it has a population of 2,455,543 people and a land area of 7,157 km^2. The population growth rate is estimated to be 18.04% between 2001 and 2011. Figure 1 shows the geographical position of Latur. It is located at an elevation of 631 m above sea level on average.

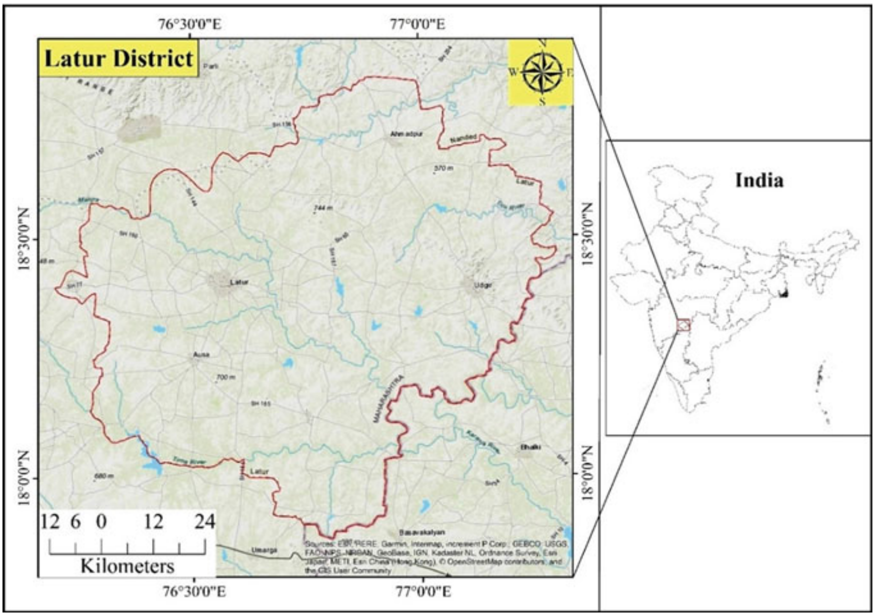

Fig. 1 Locational aspect of the study area

The regions have a tropical environment with an average precipitation of 600 mm and temperatures ranging from 24 to 39.6 °C. It is experiencing extended drought conditions, which are wreaking havoc on the region's vegetative cover. Because of the chemical nature of the soil, the region experiences cracking throughout the summer months. The three largest water sources in Latur are the Sai weir, Sai Barrage, and Dhanegaon Dam on the Manjra River. Other available water resources are more than 50 km away. The average rainfall during winter months is below 10 cm in the region while average rainfall during summer months is more than 80 cm (Guhathakurta and Saji 2013). Borewells are being used excessively by houses to address unmet water demand. This has increased the number of borewells, causing a water scarcity for crops and other vegetation and significant deterioration of groundwater levels.

2.2 Data Used

The US Geological Survey's (USGS) website, https://earthexplorer.usgs.gov/, provided the satellite data used in this study. The seasonal NDVI between 1996 and 2009 was computed using Landsat 5 (TM), whereas the NDVI for 2002 and 2016 was obtained using Landsat 7 (ETM+) and Landsat 8 (OLI/TIRS) satellite data. The current study focused on the seasonal drought in Maharashtra's Latur district over two seasons: pre-monsoon (March) and post-monsoon (October). Furthermore,

Table 1 Description of the satellite data used

S. No.	Date of acquisition	Satellite/Sensor	Path/Row	Spatial resolution (m)	Bands used
1	04-Mar-1996	Landsat 5 (TM)	145/47	30	4 and 3
2	14-Oct-1996	Landsat 5 (TM)	145/47	30	4 and 3
3	29-Mar-2002	Landsat 7 (ETM+)	145/47	30	4 and 3
4	23-Oct-2002	Landsat 7 (ETM+)	145/47	30	4 and 3
5	09-Apr-2009	Landsat 5 (TM)	145/47	30	4 and 3
6	03-Nov-2009	Landsat 5 (TM)	145/47	30	4 and 3
7	12-Apr-2016	Landsat 8 (OLI/TIRS)	145/47	30	5 and 4
8	21-Oct-2016	Landsat 8 (OLI/TIRS)	145/47	30	5 and 4

the district map of Latur is drawn at a scale of 1:25000 from the Survey of India (SOI) toposheet. Table 1 summarizes the characteristics of the various spectral bands available in Landsat satellite data.

2.3 Methodology

The study's methodology included using multi-spectral images to calculate remote sensing-based vegetation condition index for the analysis of seasonal drought anomaly (Fig. 2). The VCI was used to calculate long-term spatio-temporal variability in drought conditions in this study. The seasonal VCI was calculated using seasonal NDVI data and the seasonal NDVI and VCI maps were created in the ArcGIS domain. Drought grades established by the VCI were used to characterize the spatial and temporal variance of drought from 1996 to 2016. Droughts were classified into eight categories based on the literature on aridity classification standards: water bodies, severe drought, very high drought, high drought, moderate drought, low drought, and no drought as described in Table 2.

2.3.1 Calculation of Normalized Difference Vegetation Index

One of the most common and well-studied remote sensing products is vegetation indices, which use the change of electromagnetic spectrum reflected from the Earth's surface to satellite sensors. The normalized difference vegetation index (NDVI) measures the difference between near infrared and red bands to quantify vegetation (Shahfahad et al. 2021). The NDVI can be calculated using Eq. (1)

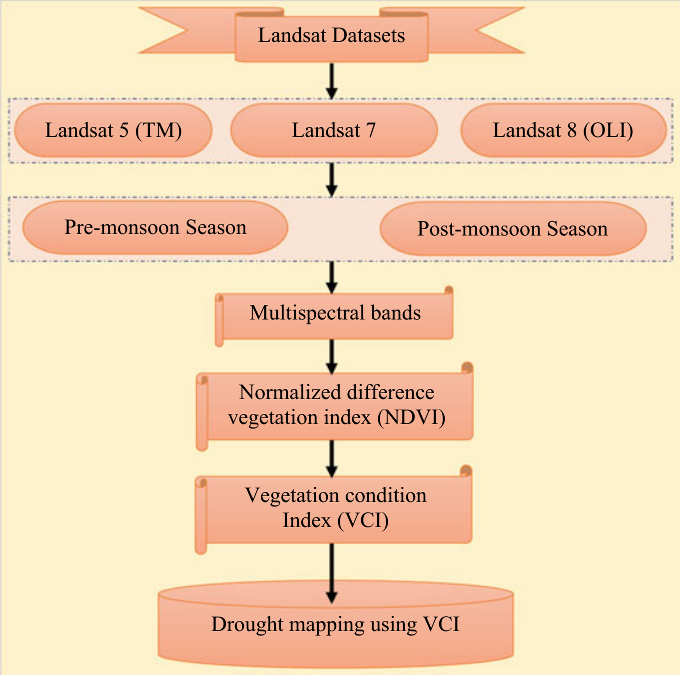

Fig. 2 Flowchart of the methodology

Table 2 Drought range in VCI modified from Kogan (1995a)

S. No.	Range	Drought class (VCI)
1	>20	Water bodies
2	20–30	Severe drought
3	30–40	Very high drought
4	40–50	High drought
5	50–60	Moderate drought
6	60–80	Low drought
7	<80	No drought

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

The NDVI scale ranges from -1 to $+1$. The NDVI values that are closer to $+1$ suggest that the vegetation is healthy. Different plant structures absorb different amounts of electromagnetic radiation. Healthy (photosynthetically active) vegetation absorbs more red wavelengths while reflecting most of the near-infrared spectrum. Stressed plant with low chlorophyll content will reflect more in the red area of the spectrum and less in the near-infrared region. As a result, the NIR and RED bands are employed to estimate vegetation attributes in terms of NDVI. As a result, NDVI can be used to infer a region's vegetation profile. Thus, NDVI can be used to infer a region's vegetation profile. Because drought has a substantial impact on vegetation, NDVI can be utilized as a fundamental indicator of drought stress on plants.

2.3.2 Calculation of Vegetation Condition Index

Kogan (1995a) created the vegetation condition index (VCI) to study drought conditions. It depicts the percentage change in the variation of the current year's NDVI index with the minimum value of the NDVI index determined from historical data. It describes the impact of drought on vegetation conditions and compares the current year's impact to historical values. VCI represents how close the NDVI of the current months is to the minimum value of NDVI calculated from prior years' data.

$$\text{VCI} = \frac{\text{NDVI} - \text{NDVI}_{\text{max}}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}} \times 100 \quad (2)$$

where NDVI_{min} is the minimum NDVI and NDVI_{max} is the maximum NDVI calculated from the Landsat satellite data.

2.3.3 Classification of Vegetation Condition Index

The drought is divided into five main classes based on VCI levels (Kogan 1995a). Low VCI values imply that the NDVI for the current year is close to the minimal NDVI value derived from long-term historical data. VCI values close to zero imply that the current year's NDVI is the lowest value derived from long-term historical values, indicating extreme dryness or poor vegetation conditions. VCI is thought to be suitable for monitoring agricultural drought in a variety of settings, including those with changing ecological conditions. The VCI value of 100% indicates that the current year's NDVI is the highest number derived from long-term historical data. VCI values less than 50% indicate dry circumstances or that the area is experiencing some type of drought, whereas VCI values near 50% suggest normal vegetation conditions, and VCI values above 50% indicate that the vegetation is healthy and the area is wet (Kogan 1995a). However, in the present study we have modified the aforementioned classes and classified the drought range in VCI into 7 classes based on the local variations in vegetation conditions (Table 2).

3 Results and Discussion

3.1 Analysis of Normalized Difference Vegetation Index

The vegetation of the south-eastern regions of Maharashtra has a significant seasonality since its rivers, such as the Manjra, Terna, and Manyar, originate in the rain shadow area of the Western Ghats. During the pre-monsoon season (March) of 1996, the NDVI is as high as 0.71 while the NDVI for the same season in 2016 decreased to 0.49 (Fig. 3). Moreover, the change in NDVI from pre-monsoon (March) to post-monsoon (October) in Latur follows a distinct spatial pattern during the complete study period. Also, the temporal analysis of NDVI analysis can distinguish the stage and vegetation conditions in a given growth period (Xue and Su 2017). Figure 3 clearly shows that the maximum NDVI value has decreased gradually with time. First, during the pre-monsoon season in 1996, the NDVI increased in several regions of the central part and north-eastern part of the study area. While, during the post-monsoon season, the vegetation index increased dramatically across the whole study area, with NDVI values reaching 0.95. Furthermore, the overall NDVI value for the pre-monsoon and post-monsoon seasons in the study area fell in 2002, but the spatial change of vegetation from one season to another remained unchanged. In the post-monsoon season of 2016, the lowest high NDVI value 0.56 was observed (Fig. 3). The low NDVI value during the pre-monsoon season in Latur is well explained by precipitation and moisture deficit. The excessive precipitation during the monsoon season (>150 mm) may result in robust plants growth in the study area during the post-monsoon season leading to high values (Fig. 3).

Furthermore, Table 3 clearly shows the pre- and post- monsoon variations in the statistics of NDVI in the study area. The highest value of both maximum and minimum pre-monsoon drought was in 1996, followed by 2002 and 2009, while 2016 is at the bottom of the chart with the lowest maximum NDVI value, indicating that the earlier two years have the most vegetation variability while the latter has the least. Furthermore, the highest and lowest maximum and minimum NDVI values for the post-monsoon season were recorded in 1996 and 2009, respectively, whereas the lowest maximum NDVI value was found in 2016. The temporal statistical analysis of NDVI in Latur indicates that natural phenomena such as drought and human activities are more sensitive to NDVI, with the lowest value in the pre-monsoon season and the highest value in the post-monsoon season for the complete study period. In terms of mean values, 1996 has the highest mean for both pre- and post-monsoon, while 2002 and 2009 are second and third, respectively, for mean pre- and post-monsoon NDVI. This demonstrates that the year 1996 has the largest coverage of both vegetation and built-up area.

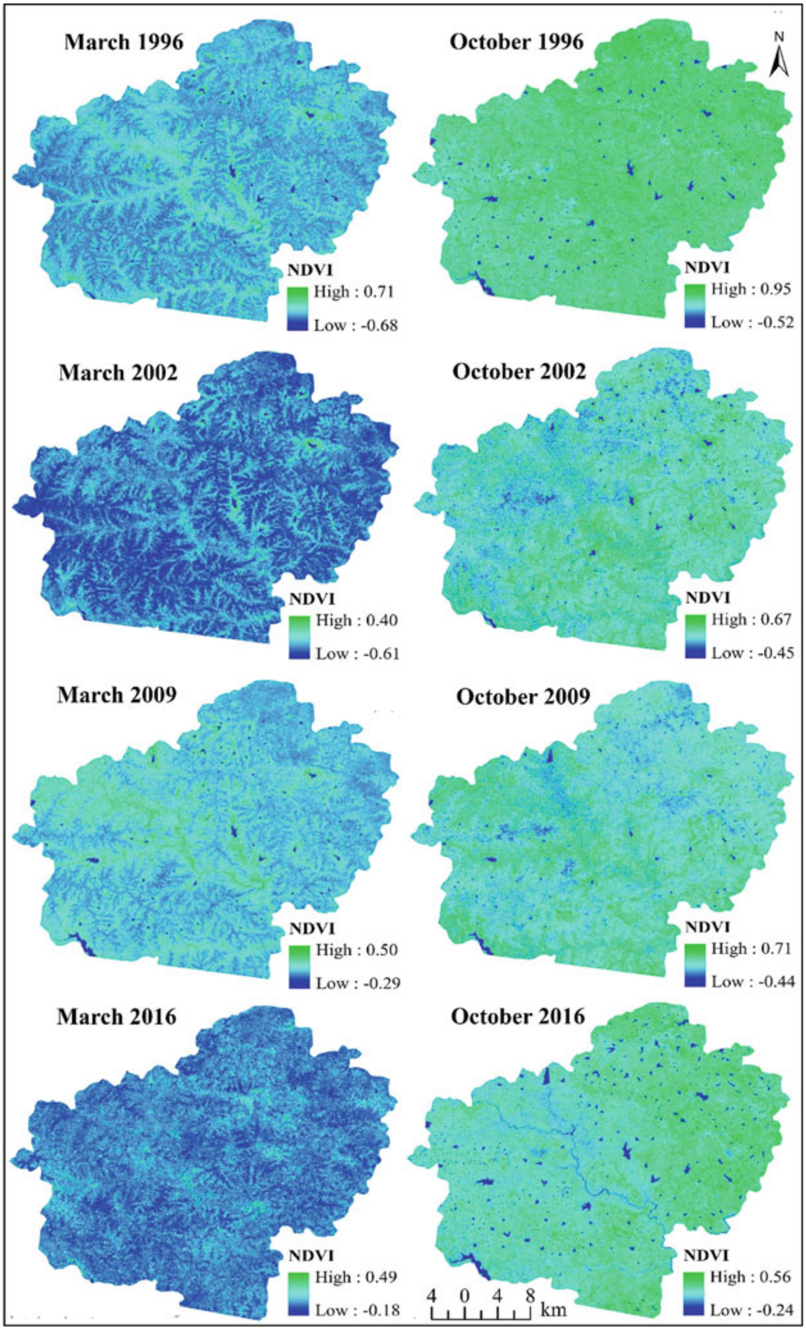

Fig. 3 NDVI for pre-monsoon (March) and post-monsoon (October) seasons

Table 3 Pre- and post-monsoon variation in the statistics of NDVI

Year	Pre-monsoon			Post-monsoon		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1996	−0.61	0.71	0.12	−0.52	0.95	0.35
2002	−0.61	0.40	0.05	−0.45	0.67	0.22
2009	−0.29	0.50	0.04	−0.44	0.71	0.26
2016	−0.18	0.49	0.08	−0.24	0.56	0.24

3.2 Analysis of VCI for Pre-monsoon Season

According to the VCI drought grade classification in Table 2, the spatio-temporal distribution of vegetation drought frequency in the pre-monsoon season in Latur was determined using Formula (2) from the year 1996 to 2016. From 1996 to 2016, pre-monsoon (March) drought was frequent, with significant regional variances. The most severe pre-monsoon drought occurred in the south-western and north-eastern regions with drought frequency ranging from very severe to high drought, affecting over 70% of the region. As illustrated in Fig. 4, the pre-monsoon VCI map of 1996 revealed that the south-western and eastern parts of Latur were experiencing extreme drought conditions. When the severe, extremely high, and high droughts were added together, it was evident that around 77.25% of the entire area was affected by drought (Table 5). In the pre-monsoon season of 2002, only 232.87 km^2 area was under no drought class, whereas 25.78 km^2 were waterbodies (Fig. 4). For the year 2009, severe drought covered the highest area (178.12 km^2) in the severe drought class (Fig. 4). From 1996 to 2016, the VCI increased on the pre-monsoon scale drastically, especially in the severe drought class (Fig. 4). The pre-monsoonal drought reached its peak in 2016, encompassing 92.02% of the region (Table 5). All three classes of drought, viz., severe, very high, and high, affected the entire region and had the greatest impact on the area (Fig. 4).

Table 4 shows a statistical analysis of Latur's pre-monsoon season under various drought classes as determined by VCI maps. The pre-monsoon VCI changes in statistics clearly show that drought conditions were extreme throughout the region during the study period. The maximum pre-monsoon figure was recorded in 1996, while the lowest was recorded in 2016. The mean VCI is continuously decreasing from 52.24 in 1996 to 40.08 in 2016, indicating an increase in the study area's drought situation. In addition, the table clearly illustrates that throughout the study period, the post-monsoon average of VCI is higher than the pre-monsoon average (Table 4).

3.3 Analysis of VCI Post-monsoon Season

Severe drought was identified in the study period, covering roughly 4.5% of the total study region, according to the long-term post-monsoon analysis. Although the area

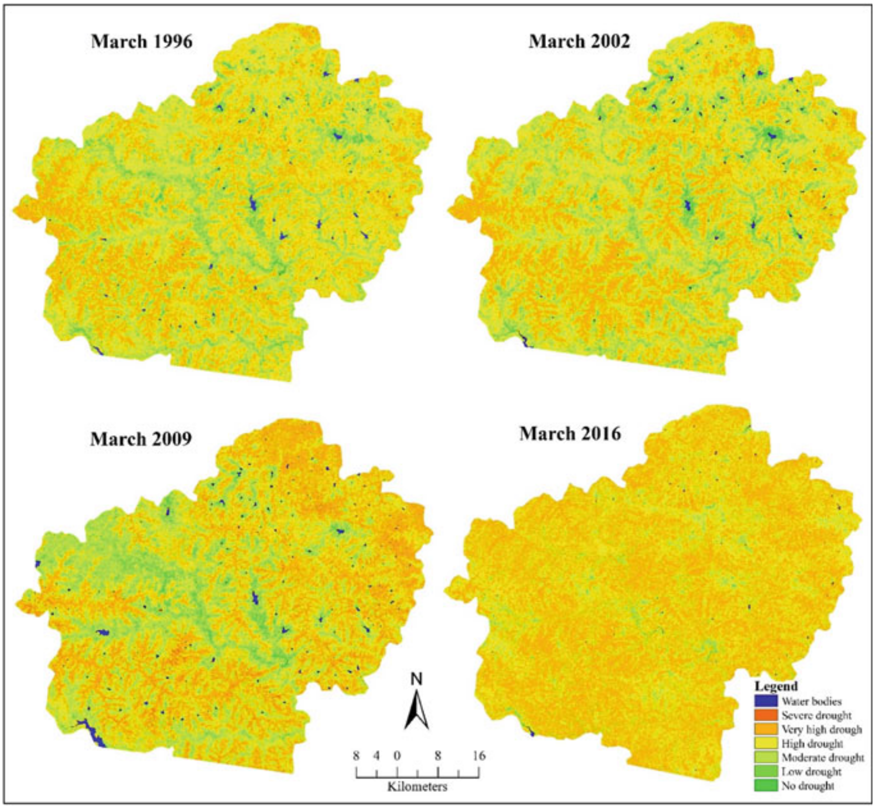

Fig. 4 Drought condition using VCI for pre-monsoon season

Table 4 Pre- and post-monsoon variation in the statistics of VCI

Year	Pre-monsoon			Post-monsoon		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1996	0.01	100.00	54.24	0.02	100.00	59.50
2002	0.00	99.99	45.93	0.01	99.99	57.66
2009	0.00	99.99	41.64	0.00	99.98	52.37
2016	0.02	99.61	40.08	0.00	99.60	50.20

affected by severe drought in the region is greater during the post-monsoon season, it only covered 60–70% of the overall study area when combined with very high and high drought classes, which is less than that of pre-monsoon drought. For the post-monsoon season period in 1996, 65.23% of the territory was under drought, with 4.8% of the region showing severe drought, and about 33% of the land being moderately impacted as well as drought-free (Table 5). Drought affected 67.78% of

Table 5 Year-wise area under drought categories based on vegetation condition index (VCI)

Season	Year	Area in km^2						
		Severe drought	Very high drought	High drought	Moderate drought	Low drought	No drought	Water bodies
Pre-monsoon	1996.00	11.50	2140.77	3326.96	994.44	353.41	230.10	36.54
	2002.00	6.99	2212.86	3258.30	905.46	352.85	232.87	25.78
	2009.00	178.12	2774.87	2272.96	1111.24	516.24	170.70	56.09
	2016.00	8.65	3964.26	2682.37	392.83	134.68	41.67	7.21
Post-monsoon	1996.00	347.41	1269.81	3010.02	1884.78	462.41	1.67	117.59
	2002.00	331.50	1854.84	2633.13	1685.11	541.20	17.72	48.51
	2009.00	216.94	2441.63	2300.63	1447.25	588.85	37.31	47.60
	2016.00	341.43	1787.77	3489.30	1341.44	168.64	2.81	100.27

the total area in 2002, but severe drought affected about 4.6% of the territory (seen in red on the map), and roughly 30% of the area was unaffected by drought. Also, the severe drought class covered the most area (216.9 km^2) in 2009 (Fig. 5). The post-monsoon scale's VCI fluctuated a lot between 1996 and 2016, especially in the severe drought category (Table 5). The area under high and very high drought categories for post-monsoon season has increased during the study period and in 2016, the post-monsoonal drought reached its apex, with 77.69% of the region affected. However, the area under high, very high, and severe drought classes was comparatively lower during post-monsoon season than the pre-monsoon season (Fig. 5). This is because, the meandering during the monsoon months is very high (>150 mm) in the region (Guhathakurta and Saji 2013) which leads to healthy vegetation growth in the regions which can be noticed in Fig. 3.

Furthermore, Table 4 illustrates a statistical analysis of Latur's post-monsoon season using VCI maps to determine various drought classes. For the post-monsoon season, the minimum and maximum VCI are gradually dropping. The post-monsoon VCI mean value, like the pre-monsoon VCI values, has been declining from 1996

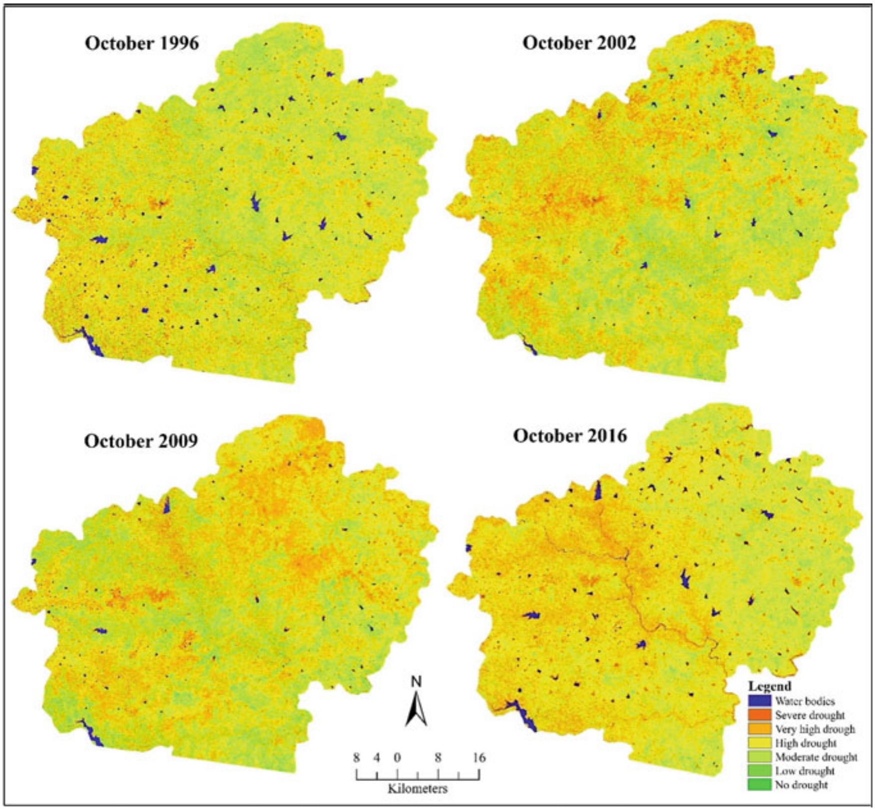

Fig. 5 Drought condition using VCI for post-monsoon season

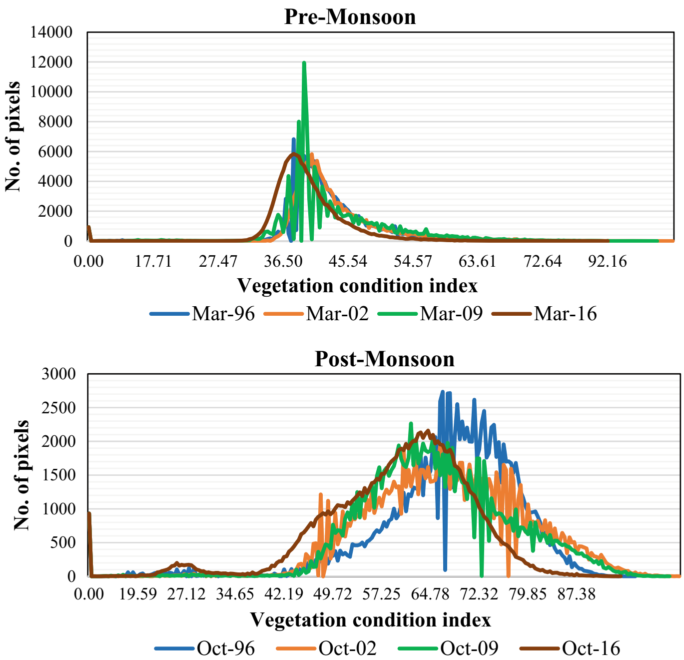

Fig. 6 Histogram of the VCI for the pre- and post-monsoon season

to 2016, indicating an increase in the general drought situation in the studied area. Although, due to the increase of vegetation after the monsoon season, the post-monsoon averages in the study area are substantially higher.

The histogram shows that while March 2016 covers a smaller number of pixels, severe drought conditions persisted, ranging from severe to moderate (20–60). The pixel coverage for the pre-monsoon season in March 2009 fluctuates between the very high (30–40) and high drought (40–50) classes, indicating that the drought situation at this time of year was area specific. The post-monsoon histogram covers a smaller number of pixels for the entire time period due to fresh vegetation development following the monsoon season. The number of pixels with VCI values ranging from 20 to 30, signifying severe drought, is seen in the post-monsoon season histogram for October 2016. In October 1996, however, low and no drought conditions (60–80 and above) covered a larger number of pixels (Fig. 6).

4 Conclusion

Drought is a natural hazard because of the negative effects it has on natural spheres, not because of the causes of such effects. The VCI proved to be an effective instrument for detecting drought and determining its onset, intensity, duration, dynamics, and effects on vegetation. Based on the findings, this study indicates that the application of the VCI approach for drought risk assessment is reliable. According to pre-monsoon season VCI maps, the drought conditions rose from 1996 to 2016. As a result, there was an increase in regions under extreme drought conditions during the study period, indicating poor vegetative condition during the pre-monsoon season.

Pre-monsoon (March) drought was common from 1996 to 2016, with considerable regional variations. Pre-monsoon droughts were most severe in the south-western and north-eastern regions, with drought frequency ranging from very severe to high drought class, affecting over 70% of the territory. Although the area impacted by severe drought in the region was higher during the post-monsoon season, when coupled with very high and high drought classes, it covered lesser area than that of pre-monsoon drought. Furthermore, statistical analysis of the pre- and post-monsoon VCI clearly demonstrated that the drought situation in 1996 and 2016 differed significantly. In the study area, the mean values for both seasons increased with time, indicating a gradual worsening of the drought situation. Although, due to the appearance of new healthy vegetations following the monsoon season, the post-monsoon season is less severe in terms of drought. In the absence of a drought study for the drought-prone district of Maharashtra, Latur, this study can provide baseline drought data. It also looks into the utility of remote sensing applications for drought research at the global, regional, and national levels. Droughts can be better predicted using satellite-based vegetation indexes combined with continuous and long-time series data.

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Sea Level Rise and Impact on Moushuni Island of Sundarban Delta (West bengal)—A Geospatial-Based Approach

Atashi Jana and Gouri Sankar Bhunia

Abstract Sea level rise (SLR) is one of the major threats to coastal areas across the world. According to IPCC, Sundarban delta is vulnerable due to climate change and natural disasters. This paper aims to delineate the erosional pattern and shifting of shorelines of Moushuni Island and its impact on the local livelihood pattern due to SLR. Multi-temporal Landsat data were used to identify the shoreline. The Union method was applied to demarcate erosion and accretion zone. Spatial overlay analysis is performed to determine the spatial correlation with the socio-economic characteristics within the study site. The net loss of the entire Sundarban island is 44 km^2 between 2001 and 2009 with an average rate of erosion of 5.5 km^2/year. Coastal erosion and accretion cause shoreline dynamic in the Moushuni island. There is a rapid shifting of the shoreline on the Moushuni island. As a result, there is a progressive reduction in land area with the breaching of embankments. The land area of Moushuni island in 2000 and 2009 was 28.923 sq km and 28.283 sq km, respectively, and the total loss of land area was 0.64 sq km with 2.28% of land loss between 2001 and 2009. Out of four mouzas of Moushuni island, Baliara mouza has lost 2.4 sq km^2 with 157 holdings approx. About 80% population of Baliara mouza are in the most vulnerable condition. The impact of SLR decreased land holding, pressure on agriculture and increased salinity on its periphery.

Keywords Moushuni Island · Shoreline · Sea level rise · Vulnerability · Landsat

1 Introduction

Coastal environment and coastal people are vulnerable to sea level rise and other climate related natural phenomena. Since 1880, the global mean sea level (MSL) has increased 8–9 in. (21–24 cm), with about a third of it happening in the past two and a half centuries. The Rising of water level depends on melting of glaciers and ice caps and thermal expansion of seawater. The global MSL in 2019 was 3.4 in. (87.6 mm)

A. Jana (✉) · G. S. Bhunia
Department of Geography, Seacom Skills University, Kendradangal, Bolpur, Birbhum, West Bengal 731236, India
e-mail: atashijana5@gmail.com

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higher than the 1993 average, making it the highest annual average in satellite history (1993–present). The rise of the global sea level between 2018 and 2019 was 0.24 in. (6.1 mm). Increase of population growth and change of settlement pattern, as well as anthropogenic subsidence, have all played a role in raising the exposure and susceptibility of low-lying coastal areas to sea level rise and coastal flooding.

Owing to the effects of other natural and anthropogenic factors such as infrastructural growth and human-induced habitat loss, attributing such impacts to SLR remains complex (Mimura 2013). Changes in coastal infrastructure, population livelihoods, cultivation, and habitability have all been noted to increase coastal risk (Nicholls et al. 2007). Attributing reported improvements and related risk to SLR, as it is for coastal environments, is challenging (Hazra et al. 2002). The country's 7,500-km-long coastline is considered the world's most vulnerable to climate change effects, with over 20% of India's population (approximately 250 million people) living within 50 km (31 miles) of the sea. The rate of sea level rise in Indian Sundarbans' in every year is 3 cm (1.2 in.) over the last four decades. Many of these environmental cascades are already happening on Sagar Island in the Bay of Bengal, which are predicted to intensify in the coming decades. In Sundarban southern islands are more susceptible to erosion where the rate of land loss of Moushuni island is 0.64 sq km. between 2001 and 2009 (Hazra et al. 2010). The embankments of Moushuni island were breached several times between 1995 and 2010 due to coastal erosion and storm surges. Breaching of embankments causes ingress of saline water and makes soil unproductive. There is a shifting of settlements of local inhabitant as days pass by Chandra (2014).

The embankments that have been eroded due to the recent rainy season are set in the Sundarbans' Moushuni Islands. Drought and heavy rainfall in recent decades, as well as growing soil salinity, have made it difficult to produce enough food to thrive entirely on agricultural practices. Felling of trees for fuel purpose accelerates erosional activity of this island. Based on the above observation, the present study aims to delineate the erosional pattern and shifting of shorelines of the Moushuni island due to sea level rise and its impact on the rural settlement.

2 Area and Location

Moushuni island is located in Namkhana block of the Kakdwip subdivision of South 24 Parganas district of West Bengal. It is a deltaic island consisting of 4 revenue villages (mouzas)—Moushuni, Bagdanga, Kusumtala, and Baliara. The Moushuni island is extended between 21° 36′ 23″ N to 21° 43′ 13″ N latitudes and 88° 11′ 00″ E to 88° 13′ 39″ E longitudes (Fig. 1). The total population of this island is 22,073 (Census 2011), covered with an area of 27.1 km^2. The Muri Ganga river is flowing in the west and north-west of Moushuni Island, Pitt's creek in the east and the Bay of Bengal in south. The physiographic features of this island include mud flats, salt marshes, sandy beaches, and dunes formed by the fluvio-marine geomorphic process. The entire island is crisscrossed by numerous tidal creeks. The soil of Moushuni

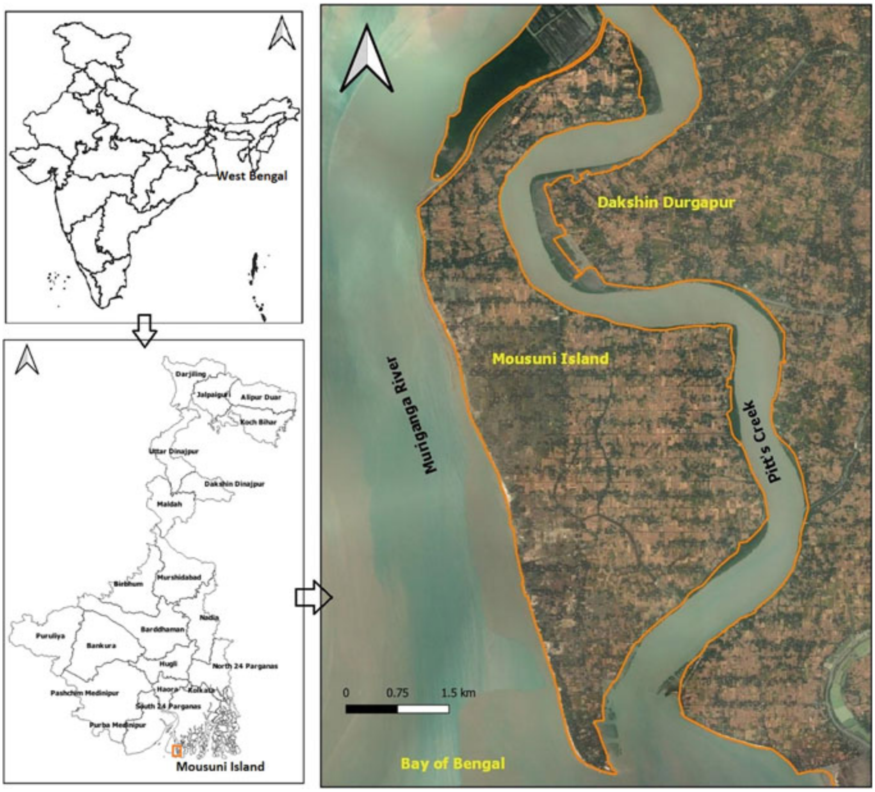

Fig. 1 The location map of the study area

island is comprised of mainly saline alluvial soil consisting of clay, silt, fine sand, and coarse sand particles. The weather of this island is almost moist with 80% humidity, annual average temperature ranges from 34 to 20 °C with extremely high rainfall. The population mainly depends on agricultural activity. In 2011, the literacy rate of this island is 80%.

3 Materials and Methods

Multi-temporal Landsat satellite data has been collected from the United States Geological Survey (USGS) Earth Explorer Community. Topographical maps (1:50,000 scale) from the Survey of India (SOI) are used as base map. Thematic mapper data for the years 1990, 2000, 2010, and 2018 were collected and registered in the UTM projection system with WGS 84 datum and the North 45 zone. Due to the differences in attitude, altitude, and velocity of the sensor platform, raw satellite images typically include several faults, such as radiometric distortion, geometric distortion, noise, and so on. Tidal gauge data were obtained from PSMSL (Permanent Service for Mean Sea Level) for analysis of the sea level rise. Population characteristics data of the study area were collected from Census of India 2011 (https://censusindia.gov.in/2011Census/pes/Pesreport.pdf). Google earth data from other satellite image sensors are available in Earth Engine as well (https://earthengine.google.com/timelapse/), downloaded at 0.25 × to illustrate the geo-visualization of the Moushuni island at a different time interval.

Shoreline of Moushuni island has been digitized based on heads-up manual digitizing method. Polygon shapefile has been created for each year. The erosion and accretion zone have been identified based on union method. All the GIS' analyses have performed in QGIS software version 3.14. The loss of the area between 1990 and 2020 is presented by a graphical representation of Excel Spreadsheets.

4 Results and Discussions

Moushuni island has four mouzas as Moushuni, Bagdanga, Kusumtala, and Baliara where Kusumtala and Baliara are more erosion prone. The western part of Kusumtala mouza and south-western part of Baliara mouza are more susceptible to erosion. Despite the reactivated delta pro gradational phase, the island system of the Hoogly-Matla estuary is experiencing a considerable amount of net land loss, according to the current observation from 1990 to 2018. Longshore variation in net shoreline change was discovered in measurements of shoreline location from year to year (Fig. 2).

The continuous threats to island are sea level rise, shifting of shorelines, erosion responsible for the forcible shifting of landowners to relocate a new place for the hungry sea. According to satellite data in 1990 the area of this island was 29.76 km^2, in the year 2000 the area was 29.17 km^2, in 2010 it was 27.37 km^2, and in 2020 the area was 26 km^2. The loss of the land area between 1990 and 2020 is 3.76 km^2 (Fig. 3).

From the analysis, there is strong evidence of subduction in the northern and southern part of the Moushuni Island (Fig. 4). In the eastern part of the island, the association between the rate of sea level rise and accretion rate is exceptionally strong. In the Northern part of Moushuni island, only erosion effect has some correlation with the sea level rise. The North-western part of the island and associated Titan Island areas are progressively decreased since 1990–2018. There is another interesting finding, where the northern part of the Jambudwip island (south-west of Moushuni island) and south of the Moushuni island has also registered erosion. However, sea level rise cannot be attributed to an accretion rate in the north-western part of Jambudwip (Fig. 5), which is an accretion region. This portion concludes that sea level rise has the least effect on accretion. It is evident from this research that sea level rise has a major effect on coastal erosion. However, it's worth remembering that, in some areas, sea level rise has a major effect on accretion processes and vice versa.

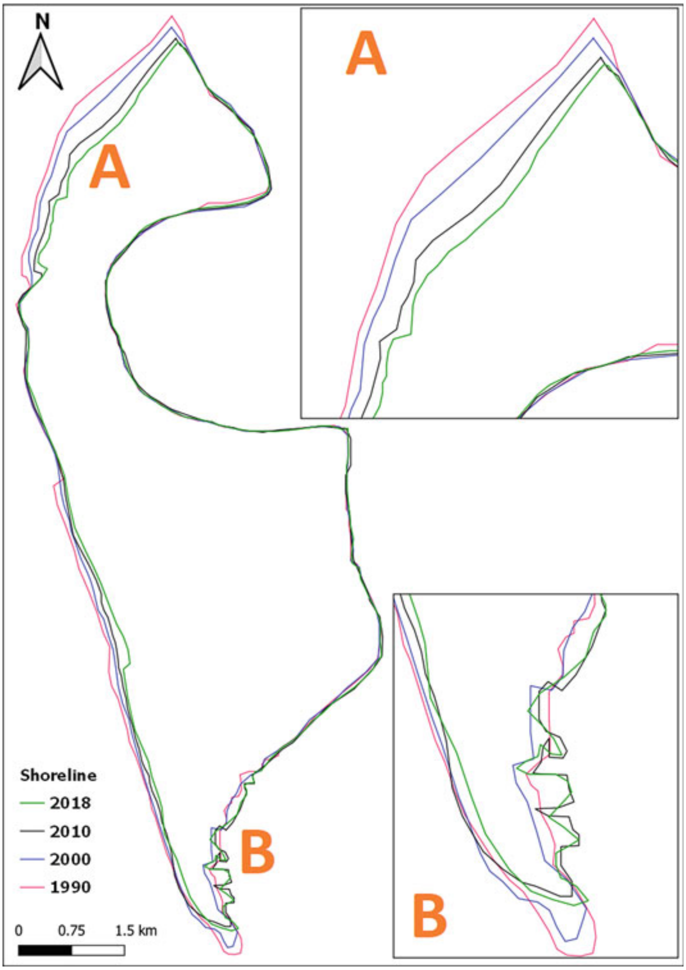

Fig. 2 Changes on shoreline in Moushuni island

5 Conclusion

Sea level rise is one of the major threats in different parts of Sundarban. Moushuni island of Sundarban is severely suffered from sea level rise, shifting of shorelines, and erosion. If this rate of erosion continues Moushuni island will sink in next 4–5 decades. According to the present study, the land loss between 1990 and 2020 is 3.76 km^2. The northern, north- western, and southern parts of the island are severe erosion prone and the rate of accretion is high in the eastern part of the island. Sea level rise has a bitter effect on socio-economic condition of Moushuni island and forces people to migrate for livelihoods. It also causes increase in salinity, responsible for changes in species composition of mangroves and decrease in extent of mangroves. Soil

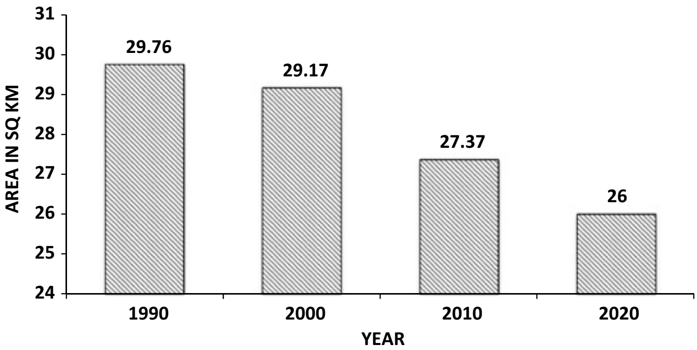

Fig. 3 Areal distribution of Moushuni island (1990–2020) estimated from Landsat Thematic Mapper data

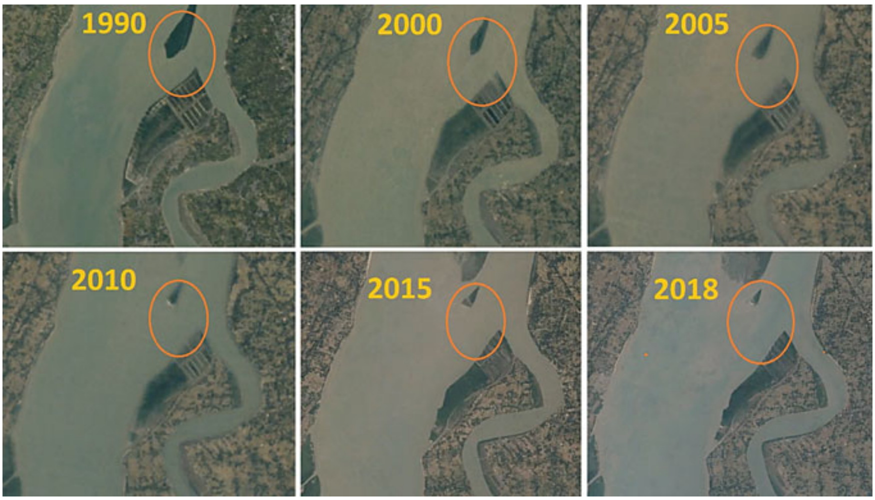

Fig. 4 Submergence of the northern part of the Moushuni island from 1990 to 2018

salinity and water logging caused by sea level rise are major problems to agricultural productivity of this island. About 89% of farming families of this island are suffered from salinization and sea water intrusion. The yield of the paddy crop is severely affected by inadequate drainage facility in the monsoon. Next to agriculture fishing is one of the major livelihoods of this region. But about 40.38% of fishing activity has been affected by engulfing of seawater. Also catch of Hilsa (Tenulosa Ilisha) is decreasing since the 80s due to climate change scenario. So, to save this island and dwellers need to take strategic plan for its proper planning and mitigation.

Fig. 5 Submergence of the southern part of the Moushuni island (1990–2018)

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Mapping of Affected Areas by Extreme Weather Events in *Kanda Tehsil* of *Bageshwar* District by GIS and RS Technique

Meenakshi Goswami

Abstract *Uttarakhand* has seen a wide range of extreme weather events over the years. *Bageshwar* district of *Kumaon Himalaya* has suffered disasters due to these extreme weather events. These extreme weather events and their impacts have been studied in *Tehsil Kanda* of *Bageshwar* district. In *Tehsil Kanda*, the villages affected by these extreme weather events from 2005 to 2015 have been mapped with GIS (Geographical Information System) and RS (Remote Sensing) technical support. The use of GIS and RS technology in disaster mapping and disaster management has been very effective with the help of demarcation and mapping of disaster-affected areas. With the help of these techniques, a zoning map of the villages affected by the most extreme weather events of *Tehsil Kanda* has been prepared. With the help of these maps, the most affected villages of *Tehsil Kanda* can be identified, thus helping in disaster management and reducing disaster risk before the disaster.

Keywords GIS (Geographical Information System) · RS (Remote Sensing) · Extreme weather events · Disaster management

1 Introduction

Uttarakhand is a mountainous state, which is mostly covered with mountains, due to being a mountainous part, many types of natural disasters are seen here. Uttarakhand has been continuously affected by many natural disasters at different times. The damage caused by natural disasters is also quite common here, mainly due to high-intensity cloudbursts, earthquakes, landslides, rupture of glaciers, etc. Major natural disasters are frequent. These natural calamities also include extreme weather events, including events such as high rainfall and cloudburst, due to these events, there is an increase in landslides in the mountainous parts which causes great loss of life. Extreme weather events are special conditions in the atmosphere that cause disaster conditions as well. Uttarakhand has been continuously affected by these extreme

M. Goswami (✉)
Department of Geography, Govt. PG College Berinag, Pithoragarh, Uttarakhand, India
e-mail: meenakshi.arjun2014@gmail.com

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seasonal events. Bageshwar district of Kumaon Himalaya has also been affected due to these extreme weather events. The impact of these extreme weather events in Kanda tehsil of Bageshwar has been studied in this research paper.

Geographic Information Systems (GIS) and Remote Sensing (RS) are advanced technologies used, which assistance can be taken in disaster management. Many researchers have used GIS and RS technology in disaster management. C. J. Westen has used Remote Sensing (RS) and Geographic Information Systems (GIS) for natural disaster management and has described the GIS and RS technical utility in natural disaster mitigation in the world in his research paper (van Westen 2010). Varun Joshi and Ashok Kumar Sharma in their research paper have used Remote Sensing and Geographic Information Systems in Disaster Management in Gangtok, Sikkim has used more ARS techniques for disaster management (Sharma and Joshi 2016). Phong Tran, Rajib Shaw, Guillaume Chantry, and John Norton have done flood risk mapping and disaster management in Vietnam with GIS technical support (Tran et al. 2009). In his research paper, Remote Sensing and Disaster Management, Antoanetta Frantzova studied how RS and GIS can be used in disaster management and how useful this technology is for disaster management (Frantzova 2010).

2 Research Methodology

In this study, disaster-affected village of Kanda tehsil of Bageshwar district has been studied, secondary data has been used in this research paper. Secondary data has been collected from the Tehsil office in Kanda. GIS and RS techniques have been used in this study, under which, Arc GIC software has been used for disaster-affected villages mapping and Google Earth and Bhuwan software have been used for location determination of disaster-affected villages. In this research paper, after analyzing the secondary data, a map and zoning of the affected areas with GIS and RS technical assistance have been done so that assistance can be taken in disaster management.

3 Study Area

Bageshwar is a district situated in the Lesser Himalayas of Uttarakhand, which has 6 tehsils, one of which is Kanda tehsil, which has been studied in this research paper. Kanda is located at 29.85° North and 79.85° East. It is located in the eastern part of Bageshwar district, in its east is Berinag tehsil, Kapkot in the north, and Gangolihat in the south. It has an average elevation of 1600 m above sea level. There are 160 villages in Kanda tehsil.

4 Findings/Results

4.1 Damage Assessment Due to Extreme Weather Events in Kanda Tehsil

In this paper, a study of the villages affected by the disaster and the damage caused by the disaster have been recorded in Kanda tehsil from 2005 to 2015, and on the basis of this study, mapping of the affected villages has been done. The studied areas have suffered a lot due to the extreme weather events in the past years, in which there has been a lot of damage to human beings, animals, houses, and crops. In these extreme events, heavy rains and cloudbursts are the major events, due to which landslides, flash floods, and land erosion disasters are seen in the study area. The damage caused by extreme weather events in the study area in the previous years is shown in Table 1 and in Fig. 1 this damage is shown through the figure as well.

From the Table 1 and Fig. 2, it is considered that due to extreme weather events in the last years, 31 houses were partially damaged in Kanda tehsil in the year 2005–06, 3 animals have been lost, and 1 family has been provided with gratified assistance. In the year 2006–07, complete damage to 3 houses and partial damage to 14 houses were observed and gratified assistance have been provided to 2 family. In 2007–08, 1 house was completely damaged, 47 houses were sharply damaged, and 33 houses were partially damaged; 2 families have been given ex-gratia assistance along with one loss of life. In 2009–10, 7 houses were completely damaged, 24 houses were sharply damaged, and 7 houses were partially damaged along with 1 animal loss; 2 families have been given ex-gratia assistance. In the year 2010–11, 4 houses were completely damaged, 61 houses were sharply damaged, and 44 houses were partially damaged along with 8 animal losses; 6 families have been given ex-gratia assistance. In the year 2011–12, 8 houses were completely damaged, 27 houses were

Table 1 Damage due to weather events during 2005–2015

Year	Damage house			Animal	Gratified assistance	Death/Injured
	Complete	Sharp	Partial			
2005–06	–	–	31	03	01	–
2006–07	03	–	14	–	02	–
2007–08	01	47	33	–	02	01
2008–09	02	14	07	–	01	–
2009–10	07	24	07	01	02	–
2010–11	04	61	44	08	06	–
2011–12	08	27	14	01	–	–
2012–13	–	26	10	–	01	–
2013–14	02	32	28	–	32	–
2014–15	02	19	06	–	–	01 (Inj.)

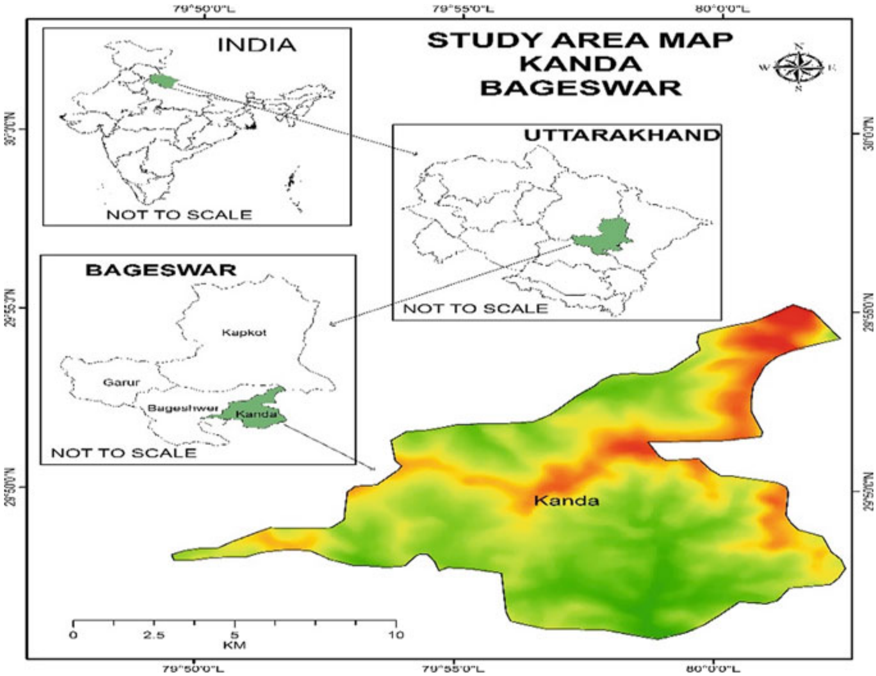

Fig. 1 Location map of Kanda Tehsil

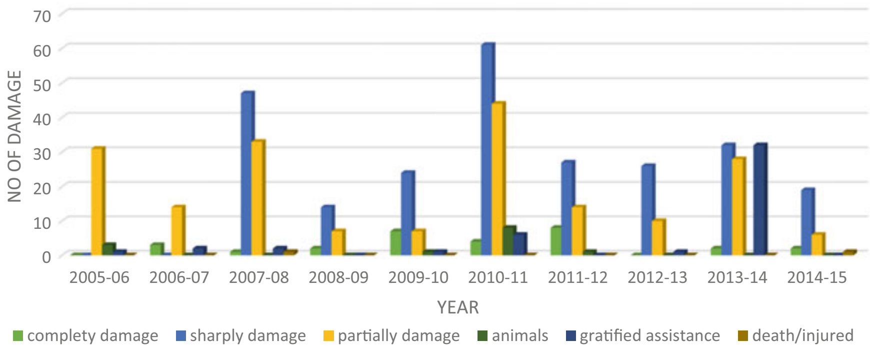

Fig. 2 Damage due to weather events during 2005–2015

sharply damaged, and 14 houses were partially damaged along with the loss of 1 animal. In the year 2012–13, 26 houses were severely damaged and 10 houses were partially damaged;1 family has been given ex-gratia assistance, 2 houses completely, 32 houses severely and 28 houses were partially damaged and 32 families have been given ex-gratia assistance in the year 2013–14. In the year 2014–15, 2 houses were completely damaged, 19 houses were sharply damaged, and 6 houses were partially damaged with one person being injured.

4.2 Affected villages of Kanda tehsil

In the past, many villages of Kanda Tehsil have been affected due to extreme weather events, due to these incidents, there has been a lot of damage in many villages, on this study, a mapping of the villages of Kanda tehsil has been done, which has been affected by most extreme weather events from the year 2005 to 2015.

4.3 Villages Affected by Extreme Weather Events During 2005–2015

From 2005 to 2015, many villages of Kanda Tehsil have been affected due to extreme weather events and there have been a lot of loss of lives and properties in these villages. The number of affected villages of Kanda Tehsil during 10 years is presented in Table 2 and bar diagram as well.

From the analysis of the Table 2 and Fig. 3, it is known that the extreme weather events in the Kanda Tehsil from 2005 to 2015 have been very high. Twenty-two villages in the years 2005–2006, 16 villages in 2006–2007, 40 villages in 2007–2008, 17 villages in 2008–2009, 25 villages in 2009–2010, 47 villages in 2010–2011, 21 villages in 2011–2012, 22 villages in 2012–2013, 32 villages in 2013–2014, and 2 villages in 2014–2015 were the most affected by these extreme weather events. In the last 10 years, 47 villages from 2010 to 2011, 40 villages from 2007 to 2008, and 32 villages from 2013 to 2014 have been most affected by the disaster. The analysis of the above table shows that Kanda Tehsil has been affected by extreme weather events

Table 2 Number of most affected villages during 2005–2015

Year	Number of most affected villages
2005–06	22
2006–07	16
2007–08	40
2008–09	17
2009–10	25
2010–11	47
2011–12	21
2012–13	22
2013–14	32
2014–15	20

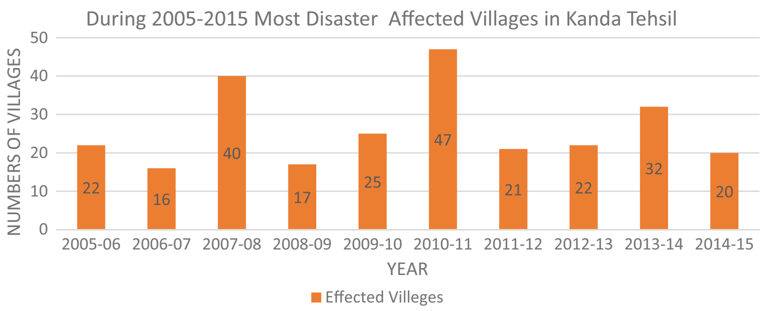

Fig. 3 Disaster Affected villages of Kanda Tehsil (2005–2015)

in the last 10 years, some villages here were the most affected by these incidents, among which Simkuna, Simgari Wajina, Jhaker, Naghar Manjila, Kandy Kanyal, Bhadura, Bhantola, Banigaon, Mahruri, Ratdhar, Siyakot, Patal, Seri, Thala, Dhapli, Malsuna, Chhana, Thanga, etc., are prominent. The most affected villages of Kanda tehsil in the last 10 years has been displayed on the map (Fig. 4).

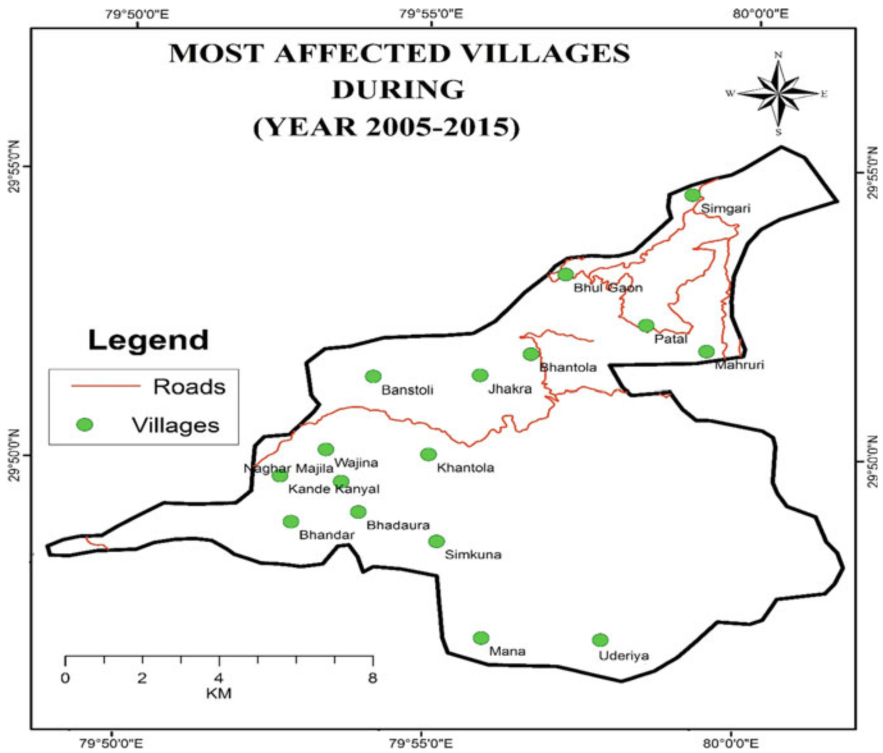

Fig. 4 Spatial representation of disaster affected villages in Kanda tehsil (2005–2015)

5 Conclusion

In the present research paper, the disasters caused by extreme weather events in the last 10 years of Kanda Tehsil have been studied and the damage caused by these incidents in the Tehsil has been assessed, and the most affected villages have been mapped, which provides assistance in disaster management in Tehsil Kanda. Due to these incidents, cloudbursts, landslides, and flash floods were quite common in this study area causing a lot of damage to many villages here. The disaster affected villages which are identified in the study could be given disaster awareness programmes, rehabilitation and mitigation strategies.

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Household-Based Approach to Assess the Impact of River Bank Erosion on the Socio-economic Condition of People: A Case Study of Lower Ganga Plain

Md Nawaj Sarif, Lubna Siddiqui, Masood Ahsan Siddiqui, Neha Parveen, Md. Safikul Islam, Shahanshah Khan, Nazreen Khanam, Sk. Mohibul, Mohammad Shariq, and Tania Nasrin

Abstract The Ganges, upstream of Farakka Barrage in the Malda district has been experiencing extensive erosion along the left bank even though it has been strongly protected. However, the erosion problem is not only restricted to the upstream section; it is widespread throughout its course in West Bengal. Hence, the risk of river bank erosion in the riparian state is increasing day by day due to changing land use patterns. In the current study, a household-level assessment of the impact of river bank erosion has been done. 600 households were surveyed for the study to assess the impact of river bank erosion on the socio-economic condition of affected people. The assessment was carried out by comparing socio-economic status before and after river bank erosion. Up to 1990, 19 households out of 600 got affected by river bank erosion, while during 1991 and 2000, the number of households who experienced the loss had increased to 424, whereas in between 2001 and 2010, the number declined to 124, and with the subsequent years of 2011–2018, it further reduced to 33. Till 1990, people who suffered river bank erosion were less affected while during 1991–2000, the reduction in average monthly income reflected the disaster's impact. In comparison to the previous two time series, the reduction in 2001–2010 was greater. On the other hand, among all the time series, the reduction in mean monthly income from 2011 to 2018 was the greatest. As a result, it can be said that the affected people's income rate had recovered over time. The recent river bank erosion gave residents, a greater negative impact on monthly income. Among 600 households, 92.16% household lost their agricultural land due to river bank erosion. The overall change from kacha house to semi pucca was 38.20%, and the change from semi pucca to kacha was 1.5%. The rebuilt from semi pucca to kacha was 0.20%. The difference between kacha and pucca was 1.5%. Only 0.20% of the 600 homes were converted from pucca to semi-kacha. Hence, the study revealed that due to river bank erosion, people were affected in terms of every socio-economic aspect.

Md N. Sarif · L. Siddiqui (✉) · M. A. Siddiqui · N. Parveen · Md. S. Islam · S. Khan · N. Khanam · Sk. Mohibul · M. Shariq · T. Nasrin
Department of Geography, Jamia Millia Islamia, New Delhi, India
e-mail: lsiddiqui@jmi.ac.in

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1 Introduction

Natural hazards are the physical events that have the potential to damage properties, loss of life, and disrupt social and economic activities (Ignacio et al. 2015). The impact of disaster is not only controlled by its physical condition, but also the sort of interaction between man and nature; changing land use patterns, economic activities, rising settlements, and pressure on resources are all having an impact on the man–nature relationship in multiple dimensions. Therefore, with the changing man–nature relationship, the repercussions such as the number of morbidities, mortalities, property losses, and structural losses are increasing (Ahsan and Warner 2014; Parveen et al. 2021). Though the researches on the impacts of natural hazards on human beings have been prevailing in the scientific community, with the development of the concept of vulnerability, these issues are profoundly discussed in social sciences too (Ignacio et al. 2015).

River bank erosion is a conventional mechanism to shape the river course wherein persists various processes at different spatial and temporal scales. These mechanisms are controlled by several environmental factors of natural and anthropogenic origin. Bank erosion, however, occurs greatly in meandering rivers, and the worst impact of river bank erosion in the long term could be observed along the river Ganga and Brahmaputra (Dewan et al. 2017; Das et al. 2017). One of the miserable impacts of river bank erosion is human displacement which is also considered a push factor for forced migration (Das et al. 2014). Many villages lost their existence after being engulfed by the river Ganga in Malda and Murshidabad districts (Laha 2015).

The rate and amount of river bank erosion by the Ganga River varies in the study area (Fig. 1). However, the amount of land loss alone could not represent the entire picture of the disaster, and to analyze the ramification of river bank erosion on socio-economic conditions, there should be assorted parameters, such as economic loss, infrastructural loss, degradation of social status, increasing social and economic insecurity, etc. The growing population in the study area along the river Ganga has increased the risk of a severe impact on people's life. Based on previous scientific researches, severe erosion might occur in any part of the river.

Ganga within the study area at any time can cause a huge loss (Das et al. 2014; Ghosh and Sahu 2018; Mukherjee 2011; Sinha and Ghosh 2012). In order to understand the adaptive and coping mechanism for river bank erosion, it is indispensable to assess the impact of a past event of the disaster. For policymakers, assessment of the socio-economic vulnerability is crucial to study for disaster risk reduction. Since, there is limited research that has been conducted to assess the socio-economic vulnerability induced by river bank erosion that quantifies the domains such as exposure, sensitivity and adaptive and coping capacity. Hence, the main objective of the current

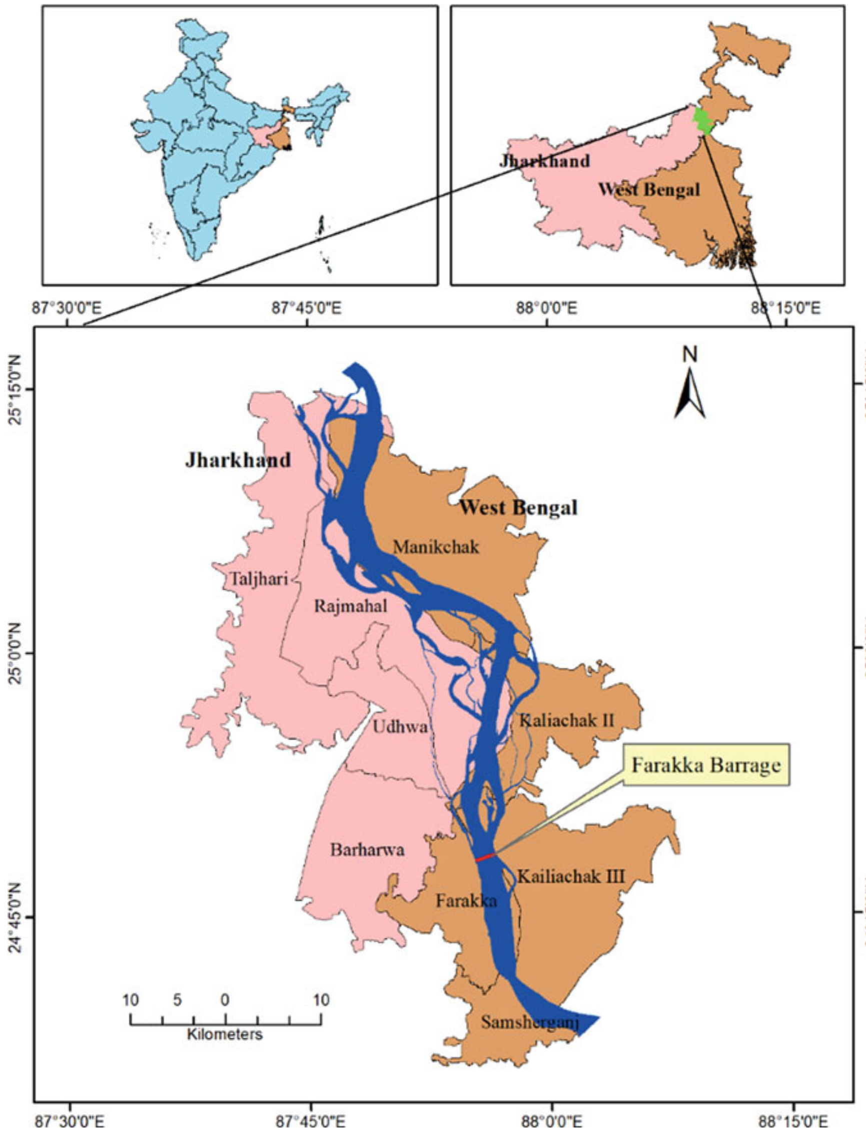

Fig. 1 Location of the study area

study was to assess the impact of river bank erosion on socio-economic condition of the people.

2 Research Methodology

2.1 Selection of the Unit and Households

Based on river bank morphometric analysis and susceptibility zonation, the affected areas due to river bank erosion was identified (Sarif et al. 2021). Focused Group Discussion (FGD) was made from the study area, each FGD consisted of 7 members who were more than 30 years old and directly affected by the bank erosion. These focused groups helped to shape the idea of the impact of river bank erosion on the socio-economic condition and its spatial distribution in the study area (Ahsan and Warner 2014). A pilot survey was done to observe the affected areas which gave the idea for selecting the unit and household. Thus, the unit and households were selected based on three layers:

i. Morphometric analysis of the river and assessment of susceptibility zonation,
ii. Focused Group Discussion (FGD), and
iii. Pilot survey

Hence, 5 blocks from the districts of Malda and Murshidabad in West Bengal were taken for the study. These blocks are Farakka and Samsherganj from Murshidabad district and Kaliachak III, Kaliachak II, and Manikchak from Malda district. In the next stage, 6 Mouzas from each block were selected along the river bank. Hence, a case study was employed in 30 Mouzas, from each Mouza, 20 affected households were selected (Table 1 and Fig. 2). Therefore, 600 households were interviewed for the collection of socio-economic data.

2.2 Before and After the River Bank Erosion

Before river bank erosion is considered that year when a household last time faced erosion while after river bank erosion referred to the year at the time of the household survey. Some of the indicators such as monthly income, area of agricultural land, condition of the house, size of homestead land, number of rooms, etc., were used as parameters to assess socio-economic condition. The condition of these indicators was compared in respect of before and after river bank erosion.

2.3 The Time Series

The time series analysis helps in assessing the coping ability of the people in case of occurrence of disaster like river bank erosion, with respect to time. For the analysis of the level of impact of river bank erosion with respect to time, the 600 households are categorized into four-time series. The first time series belongs to the people

Table 1 Mouzas for primary household survey

Sl. No.	Mauza	Block	District	State
1	Gabindarampur	Farakka	Murshidabad	West Bank
2	Farakka	Farakka	Murshidabad	West Bank
3	Baniagram	Farakka	Murshidabad	West Bank
4	Kuli	Farakka	Murshidabad	West Bank
5	Arjunpur	Farakka	Murshidabad	West Bank
6	Paranpara	Farakka	Murshidabad	West Bank
7	Anupnagar	Samsherganj	Murshidabad	West Bank
8	Lalpur	Samsherganj	Murshidabad	West Bank
9	Chachanda	Samsherganj	Murshidabad	West Bank
10	Jaladipur	Samsherganj	Murshidabad	West Bank
11	Dhusaripara	Samsherganj	Murshidabad	West Bank
12	Durgapur	Samsherganj	Murshidabad	West Bank
13	Par Deonapur	Kaliachak III	Malda	East Bank
14	Sujapur Mandai	Kaliachak III	Malda	East Bank
15	Chak bahadurpur	Kaliachak III	Malda	East Bank
16	Jagannathpur	Kaliachak III	Malda	East Bank
17	Palgachhi	Kaliachak III	Malda	East Bank
18	Sultanganj(P)	Kaliachak III	Malda	East Bank
19	Navagram	Kaliachak II	Malda	East Bank
20	Panchanandapur	Kaliachak II	Malda	East Bank
21	Birodhi	Kaliachak II	Malda	East Bank
22	Shukurullapur	Kaliachak II	Malda	East Bank
23	Jotkasturi	Kaliachak II	Malda	East Bank
24	Joananta	Kaliachak II	Malda	East Bank
25	Dharampur	Manikchak	Malda	East Bank
26	Narayanpur	Manikchak	Malda	East Bank
27	Paschim Naraynpur	Manikchak	Malda	East Bank
28	Dakshin Chandipur	Manikchak	Malda	East Bank
29	Harachandapur	Manikchak	Malda	East Bank
30	Naobarar Jagir	Manikchak	Malda	East Bank

who were affected by river bank erosion up to 1990, second is within the time span of 1991–2000. The third series is between 2001 and 2010, while the fourth time series is after the years 2011–2018. The purpose of the division of the surveyed households according to the time series was to assess the impact of bank erosion more qualitatively.

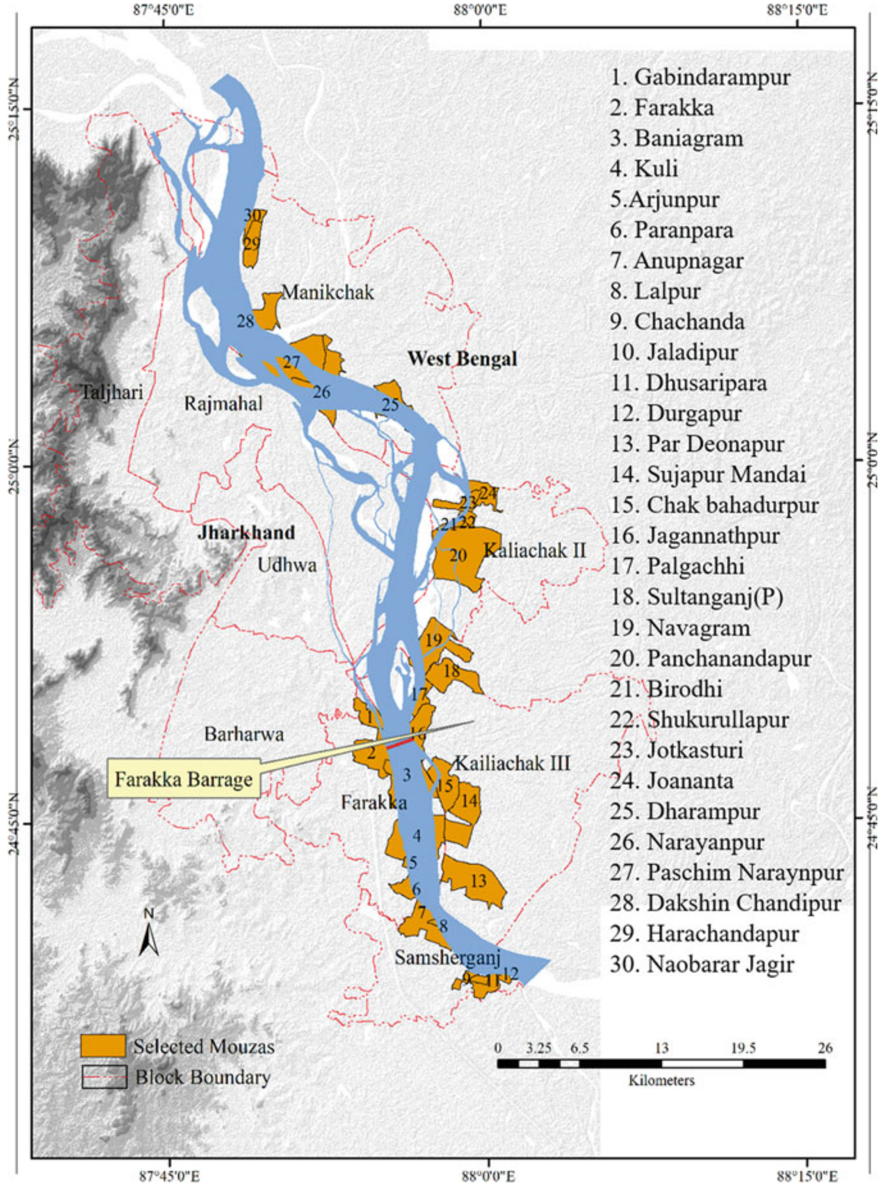

Fig. 2 Mouzas for primary household survey

2.4 Analysis of Indicators

The information collected from a primary survey about the change in occupation, house types, and the number of rooms were analyzed and converted into percentages so as to evaluate the change in the condition of these indicators after the impact of bank erosion. Changes in the monthly income, agricultural land, homestead land, and distance from the old house were also calculated by descriptive statistics.

2.5 Adjustment of the Income Value

As the data deals with different time series, the income value was different. For comparative analysis of the monthly income of households, the money value of households for different years was adjusted for a common year, i.e., 2018. The following formula has been used for adjusting the value of money according to the inflation rate of India (1):

$$x\ year\ value = \frac{CPI\ in\ x\ year}{CPI\ in\ y\ year} \times value\ for\ y\ year \tag{1}$$

whereas CPI = Consumer Price Index.

3 Results and Discussion

3.1 Impact on Livelihood

Up to1990, 19 out of the total surveyed 600 households got affected by river bank erosion, while between 1991 and 2000, the number of households who experienced the loss had increased to 424, whereas between between 2001 and 2010, the number declined to 124 and during the years of 2011–2018, it further reduced to 33. It can be observed in Fig. 3, that up to 1990, people who were living in the Farakka and Samsherganj region faced displacement as a consequence of river bank erosion. From 1991 to 2000, a huge number of households experienced losses due to river erosion in the region of Farakka, Samsherganj, Manikchak, and Kaliachak II. In the time span of 2001–2010, the worst affected block was Kaliachak III in comparison with Kaliachak II and Manikchak blocks which have also suffered severe erosion, whereas relatively, Farakka and Samsheganj blocks observed less damage (Fig. 3). Few households have faced river erosion in Farakka, Samsherganj, and Kaliachak III blocks during the period of 2011–2018. Figure 3 clearly indicates that Kaliachak III has been experiencing severe river bank erosion since 1991.

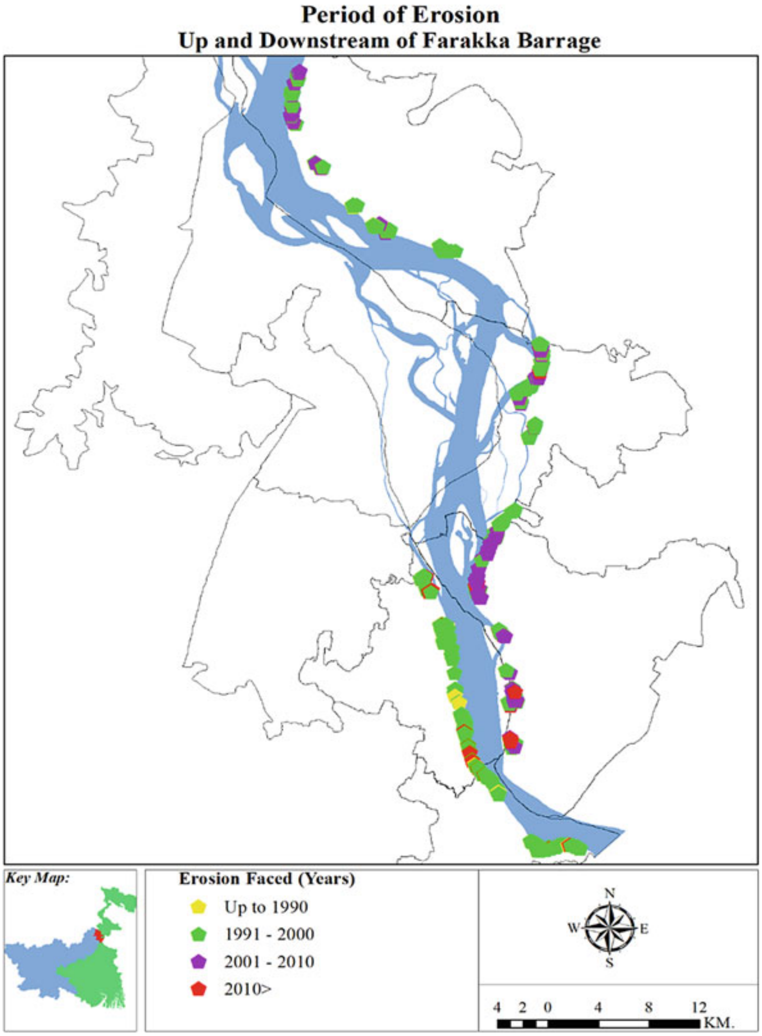

Fig. 3 River bank erosion faced by the habitants in different time period

3.1.1 Change in Occupation of the Households Due to Erosion—Up to 1990

The majority of those people who were affected by bank erosion prior to 1990 are still working in their old occupations. According to the victims' narration, they lived in tents for few months after losing their houses and sources of income due to bank erosion. They narrated that it was very difficult for them to survive, especially in the first few years, and they had to struggle to start their life again. Some of the sufferers reported that they had faced starvation as they did not had any food items or other required items of basic needs. Most of them became migrant labourers at that time. Some of them reported that they had to change their occupation shortly after the disaster of bank erosion, but they were able to practice their old occupation after a few years. After many years of erosion faced by the dwellers up to 1990, the situation is somewhat better now. The change statistics of occupation of inhabitants show that only 10.5% who lost their cultivated land became agricultural labourers. The rest of them gradually returned to their previous occupation (Table 2).

3.1.2 Change in Occupation of the Households Due to Erosion (1991–2000)

About 1.9% of people changed their occupation from cultivators to business from 1991 to 2000. Cultivators were replaced by the agricultural labourers, daily labourers, and out migrant labourers, respectively, by 9.7%, 2.8%, and 0.5% of the population. As a result of the river bank failure, cultivators were forced to become agricultural labourers because they had lost their agricultural land. After the bank erosion, 2.4% of daily labourers migrated to another state of the district due to lack of income opportunities during this time period. However, 1.2% of people returned to their hometown to work as daily labourers (Table 2).

3.1.3 Change in Occupation of the Households Due to Erosion (2000–2010)

From 2001 to 2010, the affected people changed their occupations due to river bank erosion, from cultivators to business by 7.30%, agricultural labourers by 9.70%, daily labourers by 2.40%, and out migrant labourers by 1.60%. 0.8% of the population switched from business to daily labourers in the area. While among the daily labourers in the locality, 1.60% became businessmen, and 0.80% changed their occupation to agricultural labourers (Table 2).

3.1.4 Change in Occupation of the Households Due to Erosion (2011–2018)

During the period 2001–2018, 9.1% of people changed from cultivators to labourers in the locale. While 3% of people converted into labourers and 3% of people changed their occupation from business to labourers in the exterior part of the affected area (Table 2). Some people also changed their occupations from daily labourers to agricultural labourers in the affected area.

Table 2 Change in occupation of the habitants due to bank erosion

Period	Occupation before bank erosion	Occupation after bank erosion													
		Cultivators		Business		Agricultural labourer		Daily labourer in the area		Out migrant labourer		Private job		Other commercial establishment	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
Up to 1990	Cultivators	–		0	0	2	10.5	0	0	0	0	–	–	–	–
	Business	–	–	5	26.3	0	0	0	0	0	0				
	Daily labourer in the area	–	–	0	0	0	0	9	47.4	2	10.5	–	–	–	–
	Out migrant labourer	–	–	0	0	0	0	0	0	1	5.3	–	–	–	–
1991–2000	Cultivators	49	11.6	8	1.9	41	9.7	12	2.8	2	0.5	1	0.2	0	0
	Business	0	0	40	9.4	0	0	4	0.9	0	0	0	0	0	0
	Agricultural labourer	0	0	0	0	26	6.1	0	0	0	0	0	0	0	0
	Daily labourer in the area	0	0	10	2.4	0	0	188	44.3	10	2.4	1	0.2	1	0.2
	Out migrant labourer	0	0	1	0.2	0	0	5	1.2	24	5.7	0	0	0	0
	Private job	0	0	0	0	0	0	0	0	0	0	1	0.2	0	0
2011–2018	Agriculture	7	21.2	0	0	3	9.1	1	3	0	0	–	–	0	0
	Business	0	0	4	12.1	0	0	1	3	0	0		–	0	0
	Agriculture labourer	0	0	0	0	2	6.1	0	0	0	0	–	–	0	0

(continued)

Table 2 (continued)

Period	Occupation before bank erosion	Occupation after bank erosion													
		Cultivators		Business		Agricultural labourer		Daily labourer in the area		Out migrant labourer		Private job		Other commercial establishment	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
	Daily labourer in the area	0	0	1	3	1	3	11	33.3	1	3	–	–	0	0
	Other commercial establishment	0	0	0	0	0	0	0	0	0	0	–	–	1	3
Overall change (up to 1990–2018)	Agriculture	71	11.8	17	2.8	58	9.7	16	2.7	4	0.7	1	0.2	0	0
	Business	0	0	56	9.3	0	0	6	1	0	0	0	0	0	0
	Agriculture labourer	0	0	0	0	38	6.3	0	0	0	0	0	0	0	0
	Daily labourer in the area	0	0	13	2.2	2	0.3	257	42.8	15	2.5	2	0.3	1	0.2
	Out migrant labourer	0	0	1	0.2	0	0	7	1.2	32	5.3	0	0	0	0
	Private job	0	0	0	0	0	0	0	0	0	0	1	0.2	0	0
	Other commercial establishment	0	0	0	0	0	0	0	0	0	0	0	0	2	0.3

Source Based on primary data (2017 and 2018)

3.1.5 Overall Change in Occupation of the Households (1990–2018)

In totality, 2.8% of people switched from agriculture to business. 9.7% of cultivators became agricultural labourers, while 2.7% changed their job to day-to-day work in the area (Table 2). One percent of the business population became daily labourers in the area. While 2.2% day-to-day labourers started their own business. The results also showed that 2.5% of people who worked within the area switched to work outside the area (Table 2). Hence, during the entire time period of study, i.e., from 1990 to 2018, the result indicates that people have not changed their occupations on a large scale. However, in the case of cultivation, the change was higher as compared to other occupations due to the loss of agricultural lands.

3.2 Impact on Income

3.2.1 Change in the Monthly Income of the People Due to Erosion—Up to 1990

Up to 1990, people who faced river bank erosion in the study area experienced a maximum change of Rs. 4500 and a minimum change of Rs. −4372 in their total monthly income (Table 3). As the minimum change in value was negative, thus the monthly income grew at a negative rate. The average increase in the income for people, who changed their occupation from cultivator to other, was Rs. 3050. Figure 4 depicts the upward trend in monthly income in this group from 1990 to 2018. The mean change in the monthly income of the people who did not change their occupation was Rs. 475 which indicates positive growth (Table 3).

3.2.2 Change in the Monthly Income of the People Due to Erosion (1991–2000)

The household survey revealed that people, who changed their income from cultivators to others between 1991 and 2000, had a mean monthly income change of Rs. −941.28. The monthly income is growing at a negative rate, as shown by the mean change. The results showed the variation in the monthly income for people who changed their occupation from one category to other, i.e., the income of Rs. −3025, −686, −266, and −808 was found for people who had switched from business to other, daily labourers to other, out migrant labourers to other, and people who did not change their income respectively (Table 3). Thus, the results clearly revealed that households had experienced negative growth in income. The people are still trying to recover from the losses caused by river bank erosion as of 2018.

Table 3 Change in the monthly income of the people due to erosion—up to 1990

Period	Changed occupation	Number	Mean	Standard deviation	Standard error	Minimum amount of change	Maximum amount of change
Up to 1990	Cultivator to other	2	3050	2050.61	1450	1600	4500
	Business to other	0	–	–	–	–	–
	Agricultural labourer to other	0	–	–	–	–	–
	Daily labourer in the area to other	2	775	106.066	75	700	850
	Out migrant labourer to other	0	–	–	–	–	–
	In the same occupation	15	475.2	2391.012	617.3567	−4372	4500
1991–2000	Cultivator to other	64	−941.281	2624.881	328.1102	−7200	7700
	Business to other	4	−3025	2173.131	1086.566	−600	−5400
	agricultural labourer to other	0	–	–	–	–	–
	Daily labourer in the area to other	22	−686.364	2285.419	487.2529	−3500	7500
	Out migrant labourer to other	6	−266.667	1486.831	606.9962	2100	−2300
	In the same occupation	328	−808.11	2289.782	126.4321	−7900	10,400
2001–2010	Agriculture to other	26	-1350	2259.07	443.0402	3200	−5500
	Business to other	1	–	–	–	–	–
	Agricultural labourer to other	6	−733.33	1772.76	1772.757	1000	−3400

(continued)

Table 3 (continued)

Period	Changed occupation	Number	Mean	Standard deviation	Standard error	Minimum amount of change	Maximum amount of change
	Daily labourer in the area to other	0	–	–	–	–	–
	Out migrant labourer to other	2	−4900	1555.63	1100	−3800	−6000
	In the same occupation	89	-1719.6	3128.27	331.5964	5900	−15,800
2011–2018	Cultivator to other	4	-3750	1968.93	984.4626	-6700	−2700
	Business to other	1	–	–	–	–	–
	Agricultural labourer to other	0	–	–	–	–	–
	Daily labourer in the area to other	0	–	–	–	–	–
	Out migrant labourer to other	3	−3100	3700	2136.196	−6800	600
	In the same occupation	25	−6584	13,535.6	2707.112	−70,800	−600

Source Based on primary data (2017 and 2018)

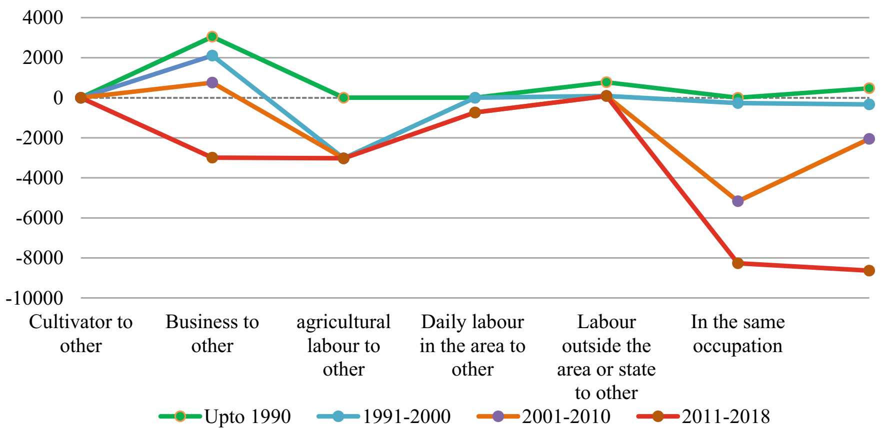

Fig. 4 Average change in the monthly income after river bank erosion

3.2.3 Change in the Monthly Income of the People Due to Erosion (2001–2010)

During the erosion period of 2001–2011, the average monthly income of people who changed their occupation from cultivator to other was reduced by Rs. 1350, until the date of the survey (2018). The change in monthly income of people, who changed their occupation from one business to another, was Rs. −733 (Table 3). Those who remained in the same occupation faced a monthly income reduction of Rs. 1719 and the standard deviation is also very high in this case (3128.27).

3.2.4 Change in the Monthly Income of the People Due to Erosion (2011–2018)

Table 3 shows the income of people who changed their occupation from cultivator to other had decreased by Rs. −3750. The minimum and maximum changes in monthly income in this group were Rs. −2700 and −6700, respectively, with a standard deviation of 1968.93. People who did not change their occupation after being affected by river bank erosion witnessed their monthly income drop by Rs. 6584 on an average, with a standard deviation of 13,535 (Table 3).

As a result, Fig. 5 depicts the impact of river bank erosion on people's economic conditions as reflected in the change statistics of monthly income. Figure 6 showed a very interesting result regarding the disaster's impact. Till 1990, people who suffered river bank erosion were less affected, while during 1991–2000, the reduction in average monthly income reflected the disaster's impact. In comparison to the previous two time series, the reduction in 2001–2010 was greater. On the other hand, among all the time series, the reduction in mean monthly income from 2011 to 2018 was the greatest. As a result, it can be said that the affected people's income rate has recovered over time. More recent impact of the river bank erosion event faced by the dwellers, higher the negative impact on monthly income has been found.

The question may arise as to why or how people who have not changed their occupation despite being affected by river bank erosion have resulted in a decrease in their average monthly income. The question is difficult to answer quantitatively. However, the facts can be revealed through a qualitative analysis based on field study and interviews with the victims. Although many people continue to work in the same occupation despite significant property losses, the size of their businesses has shrunk as a result of river bank erosion. For instance, there were many people who used to run garment businesses in their own shops, but they lost shops due to river bank erosion. There are still those affected people who sell clothes but the sizes of shops have reduced due to erosion, some afflicted individuals run the business on sidewalks, while others work as vendors. As a result, their commercial establishment's size can be explained. If a cultivator loses a significant amount of agricultural land as a result of river bank erosion, still can cultivate a small size of land. Another reason for the drop in mean monthly income is that most people have lost a lot of property, including their homestead land, yet they are gradually improving their economic situation. The

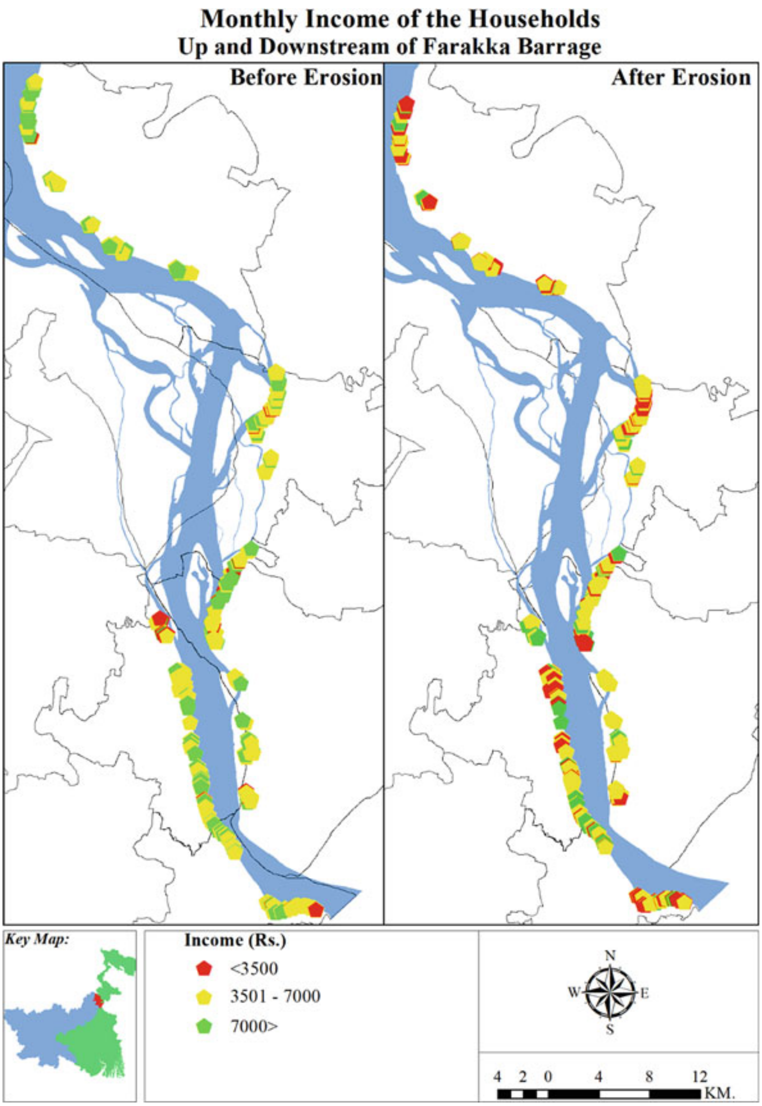

Fig. 5 Income level among the surveyed households

impact of the disaster on the mean monthly income during the reestablishment of their houses and other socio-economic conditions is reflected in the results.

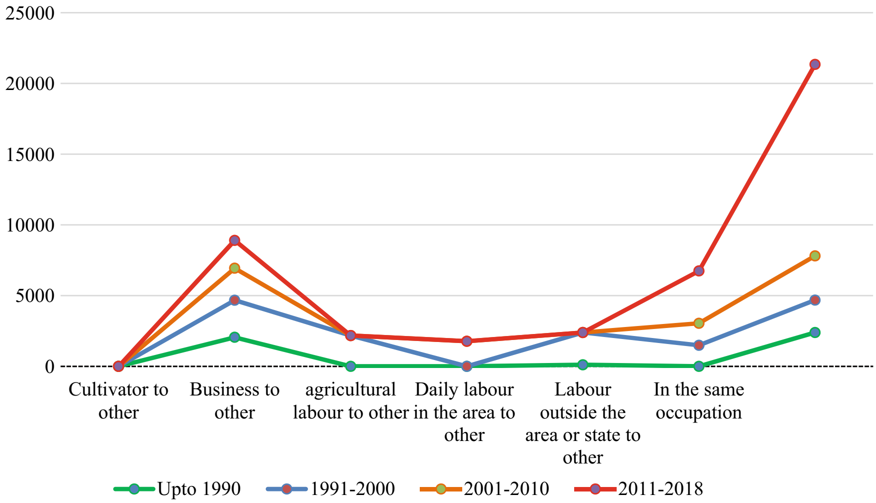

Fig. 6 Monthly average income of the households with changing occupation and remaining in the same occupation

3.3 Loss of Agricultural Land

It was attempted in this study to quantify the loss of agricultural land among 600 households. Many people have lost their agricultural land as a result of river bank erosion surveyed (Table 4 and Fig. 7). Among 600 households, 92.16% households lost their agricultural land due to river bank erosion. The average amount of cultivated land loss till 1990 was 0.09 (ha), wherein the time period of 1991–2000 the average amount loss was 0.49 (ha). Between 2001 and 2010, the average loss of agricultural land was 0.81 (ha), the highest loss among all the time series. The overall average loss of agricultural land was 0.53 (ha).

Figure 8 manifested the loss of agricultural land in the study area.

Table 4 Loss of agricultural land due to river bank erosion in different time periods

Period	% of the people loss their agricultural land	Average loss (ha)	Std. deviation
Up to 1990	89.4737	0.092747	0.145101
1991–2000	90.566	0.497611	1.286903
2001–2010	98.3871	0.81695	1.481847
2011–2018	90.9091	0.2342	0.43726
Overall	92.16666667	0.5363	1.288371

Source Based on primary data (2017 and 2018)

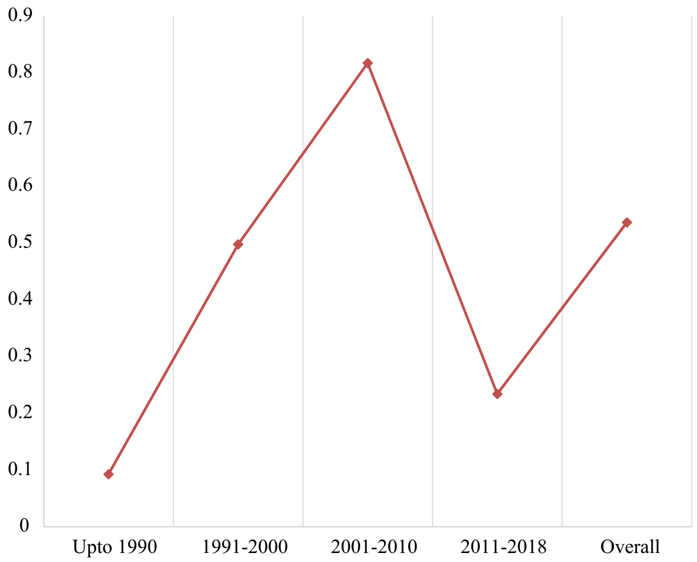

Fig. 7 Average loss of agricultural land (in hectare)

3.4 Changes in the House Type

3.4.1 Change in the House Type of the Household Faced Erosion—Up to 1990

The change from Kacha to Semi pacca house was 68.40% among the surveyed households up to 1990 that experienced the disaster (Table 5). The results show that the house type has improved over time. One of the reasons for the lack of transformation of the house type from Kacha to pacca or semi pacca to kacha could be the impact of river bank erosion. The result, on the other hand, shows a general trend in the house type. The main reason for the overall improvement can be traced back to the affected people's economic recovery prior to 1990.

3.4.2 Change in the House Type of the Household Faced Erosion During 1991–2000

Between 1991 and 2000, the percentage of households that changed from Kacha to semi pacca was 41.50, while the percentage of households that changed from Kacha to the pacca house was 1.70 (Table 5). During this time period, 0.20% of households were converted from pacca to kacha. Based on the results, the rebuilding of houses from kacha to pacca is very limited.

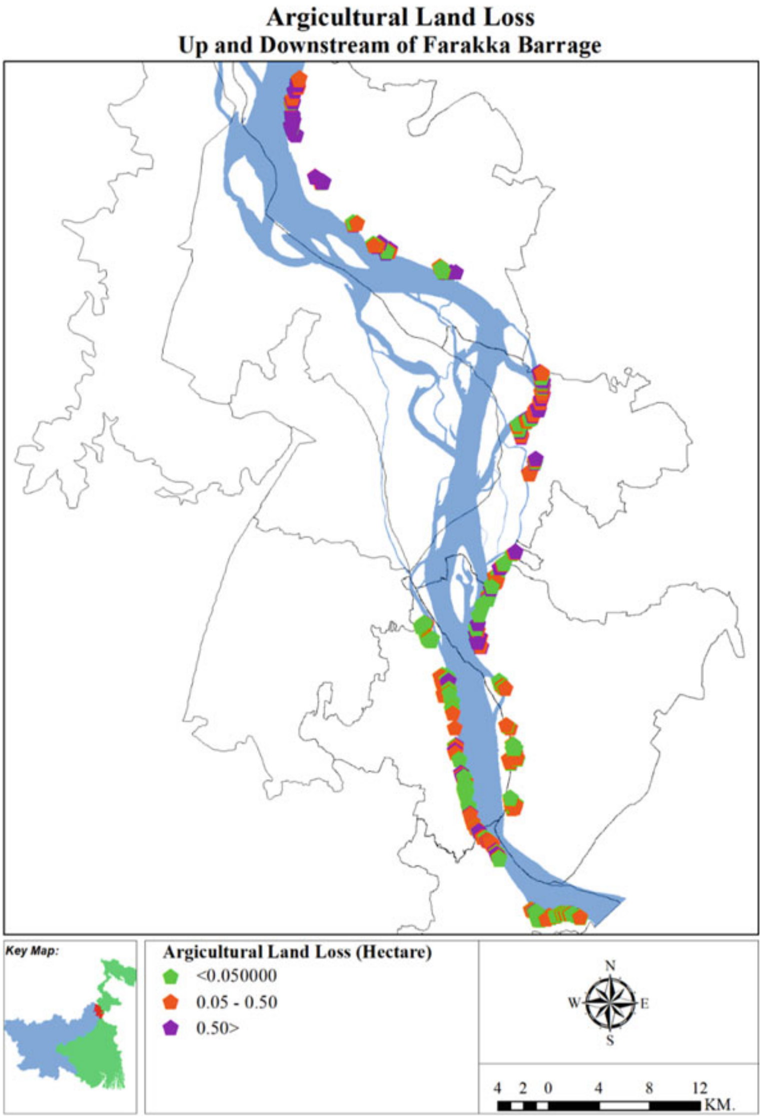

Fig. 8 Spatial variation of agricultural land loss by the habitants in the study area

3.4.3 Change in the House Type of the Household Faced Erosion During 2001–2010

According to the result from Table 5, between 2001 and 2010, the change in house type from kacha to semi pacca was 22.60%, while the change in house type from kacha to pacca was 0.80%. Households with 0.80% became semi pacca to kacha.

Table 5 Change in the house type

Period	House type before bank erosion	House type after bank erosion					
		Kacha		Semi pacca		Pacca	
		N	%	N	%	N	%
Up to 1990	Kacha	1	5.3	13	68.4		
	Semi pacca	0	0	5	26.3		
1991–2000	Kacha	5	8.3	176	41.5	7	1.7
	Semi pacca	0	0	202	47.6	3	0.7
	Pacca	1	0.2	0	0	0	0
2001–2010	Kacha	10	8.1	28	22.6	1	0.8
	Semi pacca	1	0.8	82	66.1	2	1.6
2011–2018	Kacha	1	3	12	36.4	1	3
	Semi pacca	0	0	19	57.6	0	0
Overall change in the house type	Kacha	47	7.8	229	38.2	9	1.5
	Semi pacca	1	0.2	308	51.3	5	0.8
	Pacca	1	0.2	0	0	0	0

On the other hand, 1.60% of kacha houses were converted to pacca. After rebuilding the houses, 8.10% of kacha houses and 66.10% of semi pacca houses remain in the same house type (Table 5).

3.4.4 Change in the House Type of the Household Faced Erosion During 2011–2018

During the period of 2011–2018, 36.40% of houses were rebuilt from kacha to pacca and 3% changed to pucca (Table 5). There was no pucca house that existed before river bank erosion in the surveyed area. All the house types were either kacha or semi pacca.

3.4.5 Overall Change in the House Type of the Household Faced Erosion

The overall change from kacha house to semi pacca was 38.20%, and the change from semi pacca to kacha was 1.5%. The rebuild from semi pucca to kacha house was 0.20% (Table 5). The difference between kacha and pacca was 1.5% only. Only 0.20% of the 600 households were converted from pacca to semi kacha (Table 5).

The change statistics of house types showed that the semi pacca house dominates the study area both before and after erosion. Although semi pucca is technically superior to kacha house, it is difficult to assess the current state of the house infrastructure due to poor building materials and infrastructure. Kacha houses are typically made of mud in West Bengal. However, the soil along the Ganga's bank is mostly sandy, making it unsuitable for house construction. This is the primary reason, why residents in this area prefer brick walls over mud walls. During the field survey, it was observed that the semi pucca state of the houses was not substantial.

3.5 Impact on Homestead Size

According to the findings, the size of homestead land changed by 89.47% up to 1990, with a negative change affecting 78.94% of the households (Table 6). The positive change in the 1991–2000 time series was 84.66%, while the negative change was 78.77%. The positive change between 2001 and 2010 was 83.06%, while the negative change was 78.22%. While the difference between 2011 and 2018 was 75.75% and the negative change in this time series, on the other hand, was 51.51%. In total, 84% of the homestead size changed, with 77.16% of the change being negative.

Between the total change and negative change, a significant correlation was discovered at the confidence level of 0.05 (two-tailed) (Table 7). As a result, the study revealed that the majority of the homestead land had been reduced in size due to river bank erosion (Fig. 9). Based on the interviews, people with greater homestead land had diverse types of trees such as Mango and Neem, as well as different types of vegetables. They did not have the financial means to own as much homestead land after the river bank erosion as they used to have before the disaster.

Table 6 Change statistics of homestead size in various time periods

Period	Positive change (%)	Negative change (%)
Up to 1990	89.4737	78.94736842
1991–2000	84.6698	78.77358491
2001–2010	83.0645	78.22580645
2011–2018	75.7576	51.51515152
Overall	84	77.16666667

Source Based on primary data (2017 and 2018)

Table 7 Correlation between the whole total change and negative change in the homestead size

	Change	Negative change
Change	1	0.88
Negative change	0.88	1

Source Based on primary data (2017 and 2018)

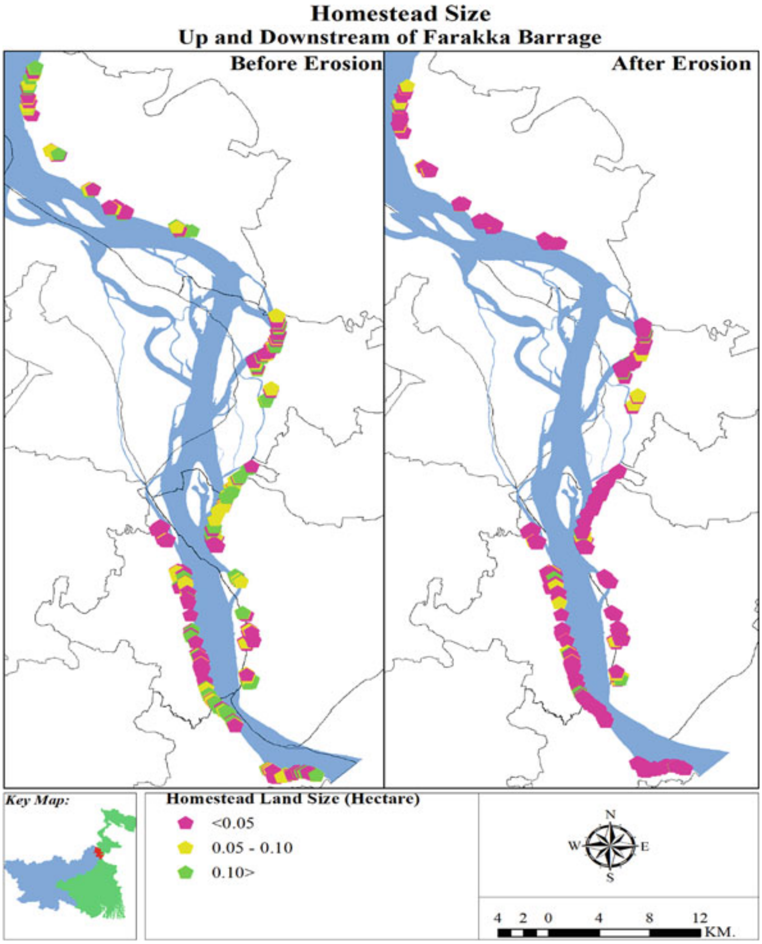

Fig. 9 Spatial variation of homestead size of dwellers before and after river bank erosion in the study area

3.6 Change in the Number of Rooms

3.6.1 Change in the Number of Rooms of the Households Which Faced Erosion up to 1990

Till 1990, people who were affected by river bank erosion had a 10.50% increase in the number of rooms from single to double and a 5.30% increase in the number of rooms from single to triple after erosion (Table 8). After the disaster, 21.10% of double-room households became single-room households. 5.30% of household room numbers had increased from two to three. Households with three rooms before

Table 8 Change in the number of rooms in the households

Period	Number of rooms before erosion	Number of rooms after erosion															
		0		1		2		3		4		5		6		7	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Up to 1990	1	–	–	3	15.8	2	10.5	1	5.3	–	–	–	–	–	–	–	–
	2	–	–	4	21.1	1	5.3	1	5.3	–	–	–	–	–	–	–	–
	3	–	–	1	5.3	4	21.1	0	0	–	–	–	–	–	–	–	–
	4	–	–	1	5.3	0	0	0	0	–	–	–	–	–	–	–	–
	5	–	–	0	0	0	0	0	0	–	–	–	–	–	–	–	–
1991–2000	1	1	0.2	54	12.7	53	12.5	7	1.7	1	0.2	0	0	0	0	0	0
	2	0	0	43	10.1	77	18.2	27	6.4	8	1.9	2	0.5	1	0.2	1	0.2
	3	0	0	21	5	43	10.1	13	3.1	4	0.9	1	0.2	0	0	0	0
	4	0	0	6	1.4	12	2.8	13	3.1	17	4	0	0	0	0	0	0
	5	0	0	2	0.5	4	0.9	0	0	0	0	1	0.2	1	0.2	0	0
	6	0	0	0	0	2	0.5	2	0.5	0	0	0	0	2	0.5	0	0
	7	0	0	1	0.2	0	0	3	0.7	0	0	0	0	0	0	0	0
	12	0	0	0	0	1	0.2	0	0	0	0	0	0	0	0	0	0
2001–2010	1	–	–	13	10.5	12	9.7	3	2.4	0	0	0	0	0	0	–	–
	2	–	–	8	6.5	21	16.9	15	12.1	2	1.6	1	0.8	0	0	–	–
	3	–	–	4	3.2	23	18.5	6	4.8	4	3.2	0	0	0	0	–	–
	4	–	–	1	0.8	2	1.6	5	4	2	1.6	0	0	0	0	–	–
	5	–	–	0	0	0	0	0	0	0	0	0	0	1	0.8	–	–
2011–18	1	–	–	3	9.1	5	15.2	0	0	0	0	1	3	–	–	–	–

(continued)

Table 8 (continued)

Period	Number of rooms before erosion	Number of rooms after erosion															
		0		1		2		3		4		5		6		7	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	2	–	–	4	12.1	7	21.2	2	6.1	1	3	0	0	–	–	–	–
	3	–	–	4	12.1	1	3	2	6.1	2	6.1	0	0	–	–	–	–
	6	–	–	0	0	1	3	0	0	0	0	0	0	–	–	–	–

the erosion now have 5.30% and 21.10% more single and double rooms, respectively (Table 8).

3.6.2 Change in the Number of Rooms of the Households Which Faced Erosion from 1991–2001

Households affected by the disaster increased their number of rooms from a single room to a double room by 12.50% (Table 8). 10.10% of households with a double room now have a single room. In this time series, 6.40% of households have upgraded to triple rooms from double rooms and 0.90% have upgraded to four rooms from double rooms. By 5% and 10%, a three-room house was reduced to a single room and a double room, respectively. People who used to have four rooms before the disaster now have single rooms at a rate of 1.40%, double rooms at a rate of 2.80%, and three rooms at a rate of 3.10%, respectively (Table 8).

3.6.3 Change in the Number of Rooms of the Households Which Faced Erosion from 2001–2010

During this time, affected households increased their number of rooms by 9.70% and 2.40% from single to double and triple respectively (Table 8). After river bank erosion, 6.50% of households-owned double rooms were adapted to single rooms, while 12.10% of the same were changed to triple rooms. Following the disaster, 18.50% of triple rooms were transformed to double rooms and 3.20% into single rooms. There was also a 3.20% increase in the number of people in triple rooms. After facing river bank erosion, people who had four rooms before the disaster reduced to single, double, and triple rooms by 0.80%, 1.60%, and 4%, respectively (Table 8).

3.6.4 Change in the Number of Rooms of the Households Which Faced Erosion from 2011–2018

In this time series of 2011–2018, the affected households went from having a single room before the river bank erosion to hold double rooms and 5 rooms by 15.20% and 3% respectively (Table 8). Before the river bank erosion, 12.10% of households that had double rooms were reduced to a single room. Though, there was an increase of 6.10% in the number of double rooms to triple in the results. People who had three rooms lost their house and homestead lands in the same time period, and their number of rooms was reduced from three to single and double rooms by 12.10% and 3%, respectively, after the disaster (Table 8).

The results of the time series unveiled how river bank erosion affects the number of rooms in the households. In some cases, the number of rooms increased, but the results showed a significant reduction in the size of the homestead. In some cases, the size of rooms should be very small, whereas findings showed an increase in the number of rooms even after being affected by river bank erosion. The result of the change in homestead land and the number of rooms indicated that the house is in poor condition. Due to a lack of homestead land, the affected people are unable to add rooms to their homes even after the number of people increases.

3.7 Average Distance of Households from Former Homestead

Due to the loss of their previous homestead lands, each of the 600 households surveyed had to relocate. The pattern of resettlement can be assessed based on the average distance from the older homestead land. Based on primary survey findings, people who were displaced by the disaster resettled within an average distance of 447.02 m in the year 1990 (Table 9). The average distance between 1991 and 2000 was 803.09 m, while the maximum distance was 977.47 m. People resettled in an average distance of 875.76 m between 2011 and 2018. As a result, the overall distance from the previous homestead land was approximately 831.83 (Table 9 and Fig. 10).

Affected people were relocated within 250 m and 251–500 m in Samsherganj and Farakka blocks, respectively. In these blocks, the majority of the land along the Ganga is urban, sub-urban, or congested. It was difficult for the affected people to

Table 9 Average distance from the old house of the people who faced erosion in the different time periods

Period	Distance (meter)
Up to 1990	447.02
1991–2000	803.09
2001–2010	977.47
2011–2018	875.46
Overall	831.83

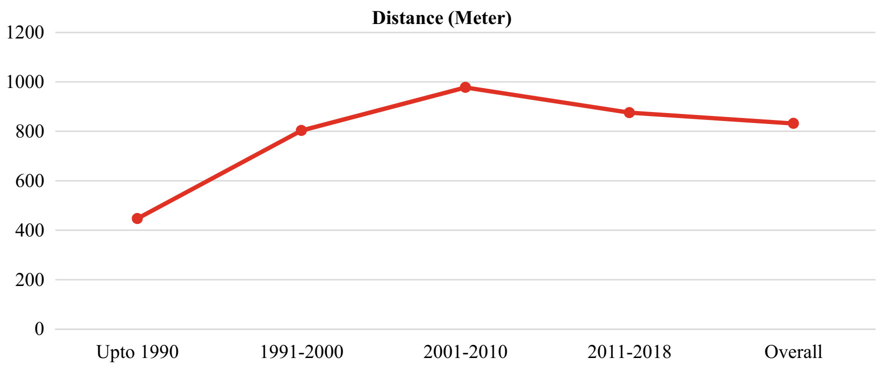

Fig. 10 Average distance from the former homestead land

buy land in the villages or towns' interiors. People in Kaliachak III, Kaliachak II, and Manikchak live more than 500 m apart because the area along the river bank of these blocks is less congested. Furthermore, most of the land along the river in these three blocks is used for agricultural practices.

The primary findings revealed that people prefer to settle along the river. The survey report of this study indicates that all the surveyed households faced river bank erosion in the past. Many of them experienced the disaster more than one time. One of the main concerns regarding the settlement of the affected people was that these people repeatedly resettle themselves near river Ganga. Due to the short distance from the river bank, people were again exposed to river bank erosion hazards. Through discussion and interviews with locals, the reason for their decision to settle near the Ganga was found. One of the most common reasons was that the soil along the Ganga is fertile and poor people usually drawn to the plains along the river. This wasn't just the case, though. After losing their homestead land, most people were unable to purchase land that was far from the river to avoid river bank failure. Lands closer to the river bank are very uncertain, unpredictable, and might be engulfed by the river at any time. As a result, the landowner's offer sells it for a lower price and affected people relocate to these cheaper lands. Though, there are other factors as well for settling along the river such as a connection to the area, relatives, and people that shouldn't be overlooked.

3.8 Impact on Mental Health

In every disaster, affected people go through stress and trauma, and in the case of river bank erosion, it was not exceptional. People who lost their homes and livelihood went through a high level of mental stress. For the survival of their family, they adopted different economic activities. The coping capacity played a vital role in the status of mental health of the victim. According to the study of Naher and Soron (2019) switching to the different occupations, suppression, homelessness, and lack of jobs, makes the victim stressed. The impact on mental health could also be observed in the people who were not affected by river bank erosion but have fear of losing homes and properties since they live nearby the river.

4 Conclusions

In the present study, the impact of river bank erosion was analyzed by evaluating various socio-economic indicators. A comparative study of socio-economic conditions before and after river bank erosion was done by simple descriptive statistics. The entire time period was divided into four time series for analyzing the impact of bank erosion on the dwellers. The result showed that more than 50% of the cultivators had to change their occupation due to river bank erosion. Most affected people converted from cultivators to marginal agricultural labourers or daily labourers. Among the other occupation, daily labourers and migrated labourers could not uplift their socio-economic condition due to heavy loss in a disaster. From 1990 to 2017–2018, no significant increase in monthly income was found, rather significant decrease in the level of monthly income was observed among the affected residents. In the time series from 2001 to 2010, the highest average agricultural land loss was noted with a significant reduction in the size of homestead land, number of rooms, and pattern of resettlement indicated that the river bank erosion in the study area was one of the biggest barriers to socio-economic development. Based on impact analysis, major issues of river bank erosion were explained in the study, which includes homelessness, poor condition of living in the river islands, land dispute, land resource management, issue of river bank protection, and lack of government aid. Though the impacts were analyzed by only descriptive statistics, the more interesting outcome of the study could be achieved by using advanced statistical techniques. The study could be used by different development authorities, regional planners, and policymakers to form strategies for mitigating the socio-economic impact of river bank erosion.

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Landslide Susceptibility Mapping of East Sikkim Employing AHP Method

Md Nawazuzzoha, Md. Mamoon Rashid, Mohammed Ihtesham Hussain, Adnan Shakeel, and Hasan Raja Naqvi

Abstract The occurrence of landslides is a frequent phenomenon in the hilly terrain of the Indian Himalayan region leading to severe environmental and socio-economic issues by distorting ecological balance and damaging human lives and property. The present work intends to identify the landslide susceptibility zones of Sikkim Himalaya using the ensembles of important knowledge-driven technique, i.e., Analytical Hierarchy Process (AHP) with Landslide Numerical Risk Factor. The Shuttle Radar Topography Mission (SRTM) DEM, Landsat 8, and GSI datasets were used. The landslide inventory map has been considered as the dependent factor and the geo-environmental factors like rainfall, slope, aspect, altitude, geology, soil texture, distance from the river, lineament, and road, Stream Power Index (SPI), topographic wetness index (TWI), Topographic Roughness Index (TRI), and Sediment Transport Index (STI), Normalized Difference Vegetation Index (NDVI) have been considered as independent factors. A landslide susceptibility map was prepared based on the AHP method and classified into high, moderate, and low-risk zones in a GIS environment. Results reveal that, about 29% of areas highly susceptible to landslide and past landslide inventories were also overlaid to observe the accuracy of susceptibility mapping.

Keywords Landslide · Susceptibility · AHP · East Sikkim Himalaya

1 Introduction

Landslides are dangerous natural hazards that occur suddenly and cause considerable damage (Guzzeti et al. 1999). It is defined as the downslope mass movement of rock, earth, and debris under the direct influence of gravity (Cruden 1991), that are triggered by the earthquake, volcanic eruptions, rainfall, slope failures, and human

Md Nawazuzzoha · Md. M. Rashid · A. Shakeel · H. R. Naqvi (✉)
Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India
e-mail: hnaqvi1@jmi.ac.in

M. I. Hussain
Department of Engineering, University of Technology and Applied Sciences, Muscat, Oman

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activities like excavation and slope cutting (Bahrami et al. 2021). Landslides belong to the most distributed natural disasters in the world with the potential to cause loss of human lives as well as severe damage to the infrastructure (Vojtekova and Vojtek 2020). Snow avalanches are a form of a landslide that happens in snow-covered areas at higher elevations and are caused by the bulk movement under gravity's impact. Identification of avalanche hazard is necessary for planning future developmental activities in mountain areas (Athick et al. 2015). Landslide occurrence is affected by two types of factors, i.e., Predisposing factors which create the condition and Triggering factors which initiate the landslide. Predisposing factors include elevation, slope, aspects, LULC, curvature, and geology, whereas Triggering factors are earthquakes, seismic activity, heavy or prolonged rainfall, excavation, and slope cutting (Guzzeti et al. 2012; Chen et al. 2017a, b; Rabby and Li 2020). Soil erosion considerably contributes to the landslide as it weakens the slope material. The rate of mean soil loss is higher in elevated zones and decreases toward the lower region, also increase in the slope gradients accelerates the rate of sediment loss (Naqvi et al. 2015; Agegnehu et al. 2020), higher elevation and steeper slope areas are more prone to landslide occurrence. The changes in land cover, biomass, and hydrologic regimes subsequently affect erosion which is more pronounced on hill slopes (Naqvi et al. 2013, 2019; Emiru et al. 2018). Analysis of the landslide and predictor factors correlation are used to estimate the susceptibility of landslide. Generally, landslide susceptibility is the spatial probability of land sliding in a given area, depending on a combination of various factors such as geology, land use and land cover, tectonics, slope, aspects, vegetation, etc. (Guzzeti et al. 2006; Wu et al. 2016). For rainfall-induced landslide, drainage density is an important susceptibility index. High drainage density indicates a highly dissected landscape that has undergone intense slope cutting (Latief et al. 2015). Landslide hazard zonation (LHZ) is an important content of landslide hazard prediction modeling. Identifying landslide-prone locations can assist decision-makers in reducing landslide risks (Boroumandi et al. 2015). The aim of landslide susceptibility mapping is to identify landslide-prone areas for the purpose of disaster management, spatial planning, and developmental process. Till now various qualitative (knowledge-driven) and quantitative (statistical) techniques and methods have been proposed for landslide susceptibility modeling (Dai and Lee 2002; Lazzari and Danese 2012). Quantitative and semi-quantitative methods consider weighing and rating based on logical tools such as AHP, fuzzy logic, combined landslide frequency ratio, and weighted linear combination (Pradhan and Lee 2009; Kayastha et al. 2013; Zhu et al. 2018). Landslide accounts for 9% of the world's disaster (Galli et al. 2008). According to various researches, China, India, Nepal, and Philippines are the most affected countries by landslides on the basis of severity, losses, and frequency of occurrence (Kirschbaum et al. 2009). Indian Himalayan Region has been the site of frequent landslides. The present study area lies in the East Sikkim Himalaya. In the past, there have been frequent and catastrophic landslides that caused heavy losses of lives and property in Sikkim. Due to the increase in population in hilly areas, economic activities like infrastructural development and construction of roads have increased making this region vulnerable to landslides (Biswakarma et al. 2020). So it is very demanding to prepare an updated landslide susceptibility map for the East Sikkim region.

2 Study Area

East Sikkim is one of the districts of the state of Sikkim. Geographically, it is located in northeastern India and a part of Sikkim Himalaya of the Indian Himalaya that lies between 27.274° N to 27.322° N latitudes and 88.778° E to 88.732° E longitudes (Fig. 1). The study area covers 954 sq km and has an average elevation of 610 m above mean sea level. The capital of Sikkim state is Gangtok city which lies in this area. It has a population of 283,583 and is one of the most populous districts among the four districts in the state (Census 2011). The climate of the district has been divided into tropical, temperate, and alpine zones. The climate is cold and humid for most of the period, and rainfall occurs almost each month. Due to its proximity to the Bay of Bengal, the Study area experiences heavy rainfall.

The mean temperature varies from 1.5 to 9.5 degree centigrade. In the entire state, fog is the common attribute between May to September and biting cold in the winter. During the month of May to October, rainfall is heavy and well distributed. The study area is mainly drained by the perennial Tista River with its tributaries such as Dik Chhu, Rate Chhu, and Rangpo Chhu. The surface area is generally roofed by forests, agricultural land, rocky and barren land, and settlements. The thickness of soil varies from steep slopes to valleys and terraces. The study area lies in the seismic zone IV and geological formation is as old as Proterozoic Eons.

3 Data and Methodology

For the accomplishment of the present work, a variety of significant data have been collected and followed different methods to achieve the landslide susceptibility mapping (Fig. 2). The rainfall data was obtained from Indian Meteorological Department, population data from the District Statistical Handbook, Census of India (2011), SRTM DEM from NASA, drainage and road networks from Open series Topographical Sheets (2015), Soil data and Geological data from the Geological Survey of India (Table 1).

3.1 Landslide Conditioning Factors

Significant and efficient mapping required an appropriate set of conditioning factors correlated to landslide events that need prior knowledge of the main contributors to the landslides (Guzzeti et al. 1999). These conditioning factors are terrain, geology

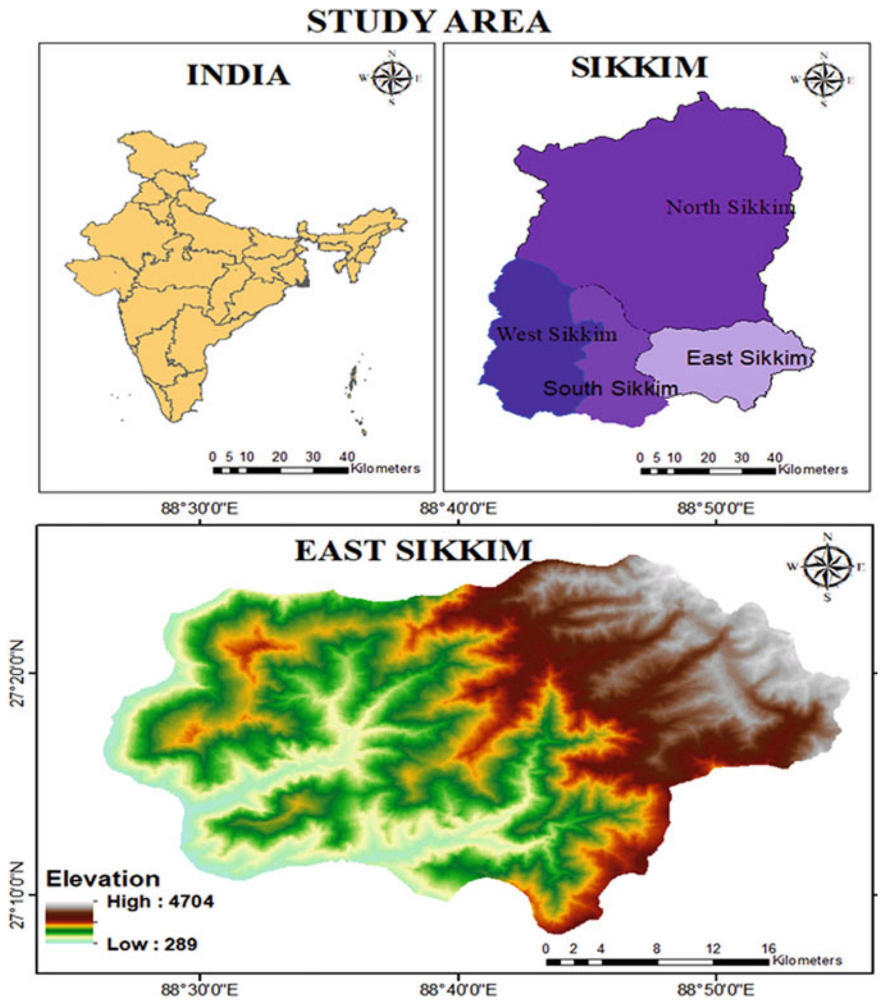

Fig. 1 Study area East Sikkim

and morphology, slope, weather conditions, vegetation density, LULC, and man-made influences. In this study, we have used 15 conditioning factors such as slope, elevation, curvature, aspect, normalized difference vegetation index (NDVI), land use land cover (LULC), topographical roughness index (TRI), topographical wetness index (TWI), sediment transport index (STI), distance from lineament, distance from the road, distance from the fault, lithology age, and Geomorphological landform.

The elevation change of each place is one of the most essential factors in the creation of soil erosion and slope mass movement. This factor has a significant impact on the direction of runoff as well as the rate at which drainage density accumulates (Hosseinzadeh et al. 2009). The highest point in the region is 4704 m, whereas

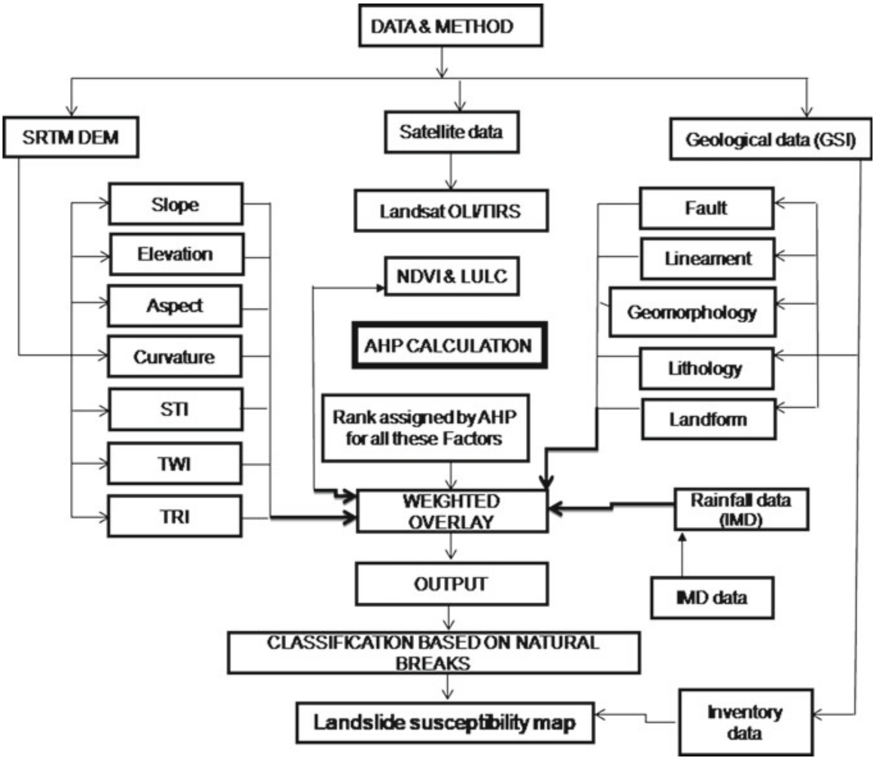

Fig. 2 Schematic flowchart depicts the datasets and methods used for the study

Table 1 Datasets and their sources employed for the study

Datasets	Data structure	Spatial resolution	Source
SRTM (DEM)	Raster	30 m	USGS, Earth Explorer, http://www.dwtkns.com/srtm30m/
Rainfall (mm)	Raster	0.05°	CHIRPS (https://chg.geog.ucsb.edu/data/chirps)
Landsat 8–OLI	Raster	30 m	(USGS) https://earthexplorer.usgs.gov/
Landslide inventory	Vector	National scale	https://bhukosh.gsi.gov.in/Bhukosh/MapViewer.aspx
Geological data	Vector	National scale	https://bhukosh.gsi.gov.in/Bhukosh/MapViewer.aspx

the lowest point is 289 m from mean sea level (MSL). In most of the landslide susceptibility studies, slope percentage is one of the most important predisposing factors (Abedini et al. 2017). Technically, as the slope rises, shear stress increases, resulting in an increase in the potential for slope instability. The aspect factor is vital in maximizing the quantity of rainfall, sun energy, and suitable wind blowing in any region, as well as reflecting the influence of soil thickness, vegetation, wetness, and other factors. Another contributor, the curvature is defined as the rate of change of slope angle or aspect which has a significant impact on slope stability. A general curvature map can be used to describe slope morphology and flow (Nefeslioglu et al. 2008). Concave, flat, and convex curvatures are the three types of curvature found in the research area.

Slope failure is complicated by the presence of lineaments (Ramli et al. 2010). Lineaments describe the weaker plane or zone, and most landslides occur in this zone (Kannan et al. 2013; Thapa et al. 2017). Active faults are significant in landslides from two perspectives: first, they are the source of earthquakes, and second, active faults play a key role in breaking stones and causing instability. The shear resistance of the slide lowers as a result of discontinuity in the geological formation, and landslides are more likely to occur. In this case, highways play the most important role in concentrating runoff, therefore, experience and current data on landslides during road reconstruction and widening demonstrate the need of including this component in landslide sensitivity zoning. In the ArcGIS environment, the three parameters stated above were determined using Euclidean distance.

The nature of land use land cover (LULC) is a key indicator of slope inconstancy which influences the earth's characteristics and causes variations in its activity. As a result, mapping the LULC and its monitoring is a critical undertaking that has a significant impact on the frequency of these dangers. Rainfall is a highly influential factor that has been considered as a landslide triggering factor. The annual rainfall map was created for this study using data from eight meteorological stations in the area and the inverse distance weighted (IDW) interpolation method was employed. Landslides are thought to be caused by a variety of factors, including geomorphology that was created using geological maps and only a few field checks (Kannan et al. 2013). In landslide susceptibility, lithology age is one of the most prominent determinant factors since different lithological units have varying weightage scores, which can provide valuable information about a region's landslide susceptibility (Yalcin and Bulut 2007). Other important and crucial aspects were also considered, and their computations were based on the following equations:

Topographic Roughness Index (TRI)

Topographic roughness index (TRI), one of the morphological factors which is broadly utilized in landslide analysis was computed by using Eq. (1).

$$\mathrm{TRI} = \sqrt{Abs\left(\max^2 - \min^2\right)} \tag{1}$$

where max and min are the biggest and smallest values of the cells in the nine rectangular neighborhoods of altitude, respectively.

Sediment Transportation Index (STI)

Sediment transportation index (STI) defines the procedure for slope failure and deposition (Eq. 2).

$$\mathrm{STI} = \left(\frac{As}{22.13}\right)^{0.6}\left(\frac{\mathrm{Sin}\beta}{0.0896}\right)^{1.3} \tag{2}$$

where β is the slope at each pixel and As is the upstream area.

Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) is an index that quantifies how topography controls the hydrological processes of an area and is derived using Eq. (3)

$$\mathrm{TWI} = \mathrm{Log}[\mathrm{A}\tan(\alpha)] \tag{3}$$

where A is the catchment area and α is the local slope gradient corresponding to a specific cell.

TWI increases with the decrease of slope and the highest TWI value is usually on floodplains (Yilmaz and Keskin 2009).

Normalized Difference Vegetation Index (NDVI)

The NDVI (Normalized Difference Vegetation Index) is a frequently used metric for describing vegetation and plant health (Chen et al. 2019a, b; Abedini and Tulabi 2018). Because the root system links to the soil and keeps it from wasting after rains, vegetation coverage helps to prevent erosion and landslides (Chen et al. 2019a, b). The NDVI was calculated using Eq. (4) and Landsat 8 level 2 images from March 7, 2018, where IR is the infrared band and R is the red band.

$$\mathrm{NDVI} = (\mathrm{IR} - \mathrm{R})/(\mathrm{IR} + \mathrm{R}) \tag{4}$$

The NDVI scale runs from 1 to 1, with a positive value of 0.2–0.8 indicating vegetation and forests, a negative value indicating water bodies, and a low positive value (0.2 and below) indicating bare land and urban areas (Chen et al. 2017a, b; Althuwayee and Pradhan 2018).

Table 2 Saaty's fundamental scale (1980)

1	Equal importance on the scale
3	Importance of moderate value
5	Significant importance
7	Extremely important
9	Extremely high influence
2, 4, 6, 8	Values in the middle of the two adjacent judgments

3.2 Analytic Hierarchy Process (AHP)

An important multi-criteria decision analysis (MCDA) method for allocating weights to specific parameters is the analytical hierarchy process (AHP) proposed by Saaty and Vargas (1998). The AHP approach employs a pair-by-pair comparison matrix. The consistency ratio (CR) value varies from 0 to 1 when the matrix is created (Saaty 1980, 1990, 1994). The AHP method can be used to do a general linear combination method to determine the potentiality index (Malczewski 1999). The fundamental scale of Saaty (1980) was used to create the pairwise matrix (Table 2). The weight of parameters was computed using the AHP approach in this example.

3.3 Application of the AHP Model

The AHP is used in this study to identify landslide vulnerability zones using a criteria-based judgment technique. For zoning landslide susceptibility, AHP can provide a good and reliable method. AHP is a single procedure that assists in determining the relative importance of various aspects based on the expert's knowledge and opinion. The AHP approach was used to assign weights to the landslide determining elements (Table 3) for this study. For mapping the landslide probability, the slope has the most weight (0.218), followed by rainfall (0.112), elevation (0.109), and TWI (0.101).

4 Result and Discussion

4.1 Mapping and Assessment of Factors Responsible for Landslide Occurrence

The various factors were considered that could be significantly responsible for landslide occurrences, and accordingly, thematic maps of all parameters were prepared for the AHP model. The most influential factor for landslide trigger is topography and all the possible thematic layers were extracted through DEM data (Fig. 3a–g). The degree of slope is more important, and the majority of the pixels indicated by blue hue

Table 3 Parameters wise weights, matrix, and consistency ratio using AHP

Parameters	Elevation	Rainfall	Slope	TWI	Curvature	Distance from fault	Distance from lineament	Distance from road	Aspect	LULC	STI	NDVI	TRI	Lithology age	Geomorphology	Weight
Elevation	1															0.109
Rainfall	0.5	1														0.112
Slope	1	1	1													0.218
TWI	0.5	1	0.33	1												0.101
Curvature	1	0.5	0.17	0.5	1											0.079
Distance from fault	0.5	0.5	0.17	0.25	0.5	1										0.048
Distance from lineament	1	0.25	0.12	0.5	0.25	0.5	1									0.053
Distance from road	0.25	0.5	0.12	0.5	0.5	1	1	1								0.064
Aspect	0.25	0.5	0.17	0.25	1	0.5	0.5	0.5	1							0.06
LULC	1	0.25	0.25	0.5	0.5	1	1	0.5	1	1						0.056
STI	0.33	0.25	0.17	0.5	0.25	1	0.33	0.5	0.17	0.5	1					0.029
NDVI	0.5	0.17	0.17	0.2	0.5	0.5	0.5	0.17	0.33	0.33	1	1				0.027
TRI	0.2	0.25	0.11	0.25	0.17	0.25	0.25	0.12	0.11	0.17	0.5	0.5	1			0.015
Lithology age	0.25	0.17	0.17	0.14	0.25	0.33	0.17	0.17	0.17	0.12	0.33	0.33	0.5	1		0.013
Geomorphology	0.33	0.25	0.14	0.17	0.17	0.5	0.25	0.25	0.12	0.17	0.25	0.25	0.5	1	1	0.015

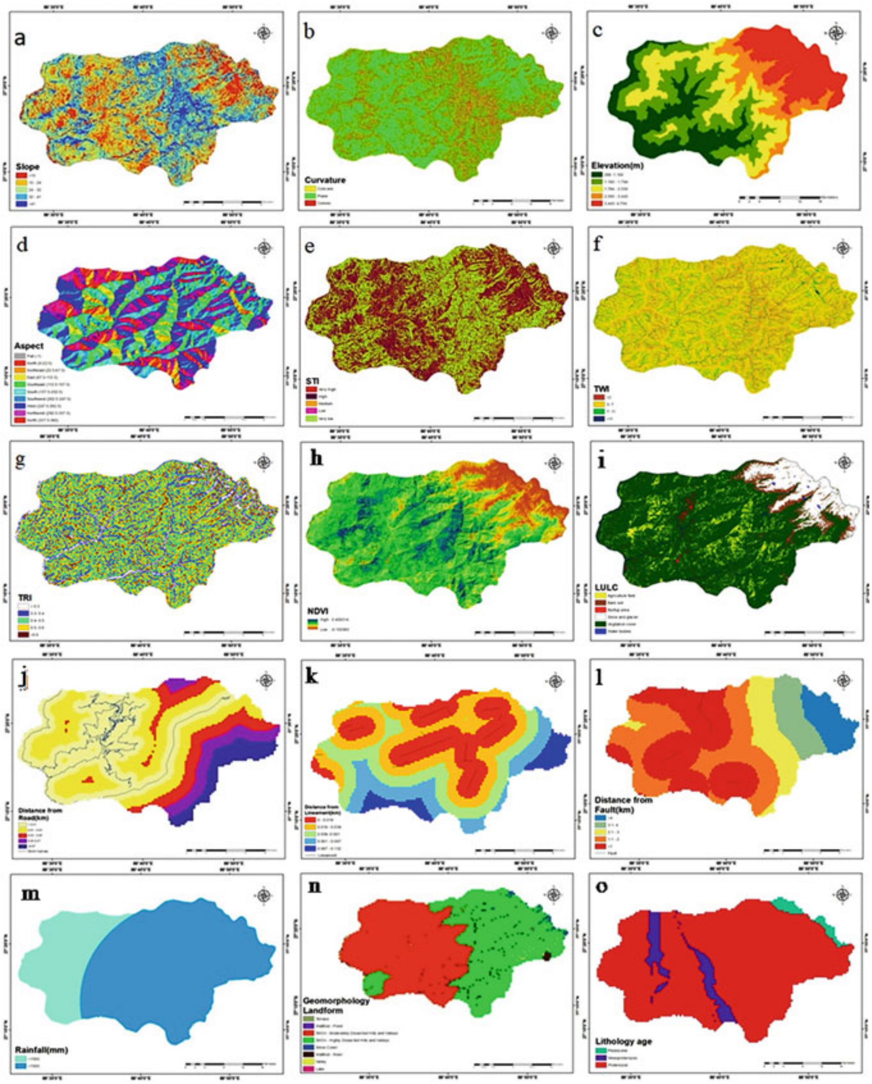

Fig. 3 Parameters such as **a** Slope, **b** Curvature, **c** Elevation, **d** Aspect, **e** STI, **f** TWI, **g** TRI, **h** NDVI, **i** LULC, **j** Distance from Road, **k** Distance from Lineament, **l** Distance from Fault, **m** Rainfall, **n** Landforms, and **o** Lithology used for landslide susceptibility mapping

had values greater than 40° and ranged between 0° to 70° (Fig. 3a). The study area has concave, plain, and convex curvatures, among them plain is dominant followed by convex and concave curvatures (Fig. 3b). The altitude of the study area ranges from 289 to 4704 m and the eastern part has the greatest variation in topography and almost half of the area has elevation >2500 m. Therefore, the study region is classified into five zones, viz., very low (289–1160), low (1160–1794), medium (1794–2550), high (2550–3443), and very high (3443–4704) (Fig. 3c). The aspect (slope orientation) affects the exposure to sunlight, precipitation, and wind, thus inversely affecting other factors that could be responsible for triggering the landslides such as vegetation cover, soil moisture, and thickness (Clerici et al. 2006). Accordingly, aspect has been categorized into flat, north, northeast, east, southeast, south, southwest, west, northwest, and north (Fig. 3d). The sediment transport index (STI), reflecting the erosive power of the overland flow depends on slope and upstream area that has been derived by considering the transport capacity limiting sediment flux and catchment evolution erosion theories (Devkota et al. 2013; Pradhan and Kim 2014). Higher STI scores denote that the area has more probability for the occurrence of a landslide (Fig. 3e), and accordingly, STI has been classified and considered in the AHP model. TWI has been calculated and results generated through DEM data denote that wherever the TWI is high, that area is considered more susceptible to landslide. The composite scores of TWI are categorized into four classes such as <2, 3–7, 7–11, and >11 (Fig. 3f). Moreover, TRI has also been calculated through DEM which too showed the similar criteria adopted in STI and TWI. The pixels under different scores of TRI have been categorized into five classes, viz., <0.3, 0.3–0.4, 0.4–0.5, 0.5–0.6, and >0.6 where higher score has more probability for the occurrence of landslide (Fig. 3g).

The NDVI and LULC thematic layers are prepared through Landsat 8–OLI dataset and these are also indicating factors that can help in finding the landslide susceptible area. The highly dense vegetative cover (>0.5), sparse vegetation (0.2–0.5), and bare land (0–0.2) areas are possibly extracted through NDVI. The NDVI scores have great potential to identify the more prone region in terms of landslide on the basis of land coverage, thus the values near 0 to 0.2 are highly susceptible (Behling et al. 2014), and accordingly, the mentioned range of NDVI values are prone within a range of our NDVI results from −0.156 to 0.459 (Fig. 3h). The spatial distribution of LULC showed that almost 2.27% of the area is covered by water bodies, 70.75% area is covered by vegetation, and 0.16 by built-up area (Fig. 3i). The remaining LULC areas such as agriculture fields (8.31%), bare lands (5.42%), and snow/glacier (13.08%) areas are exposed and make these regions highly susceptible to landslides. Other parameters such as distance from the road, lineament, and fault have also been considered and calculated through Euclidean distance (in km) into a few categories. The lowest (<0.01, <0.01, and <1) and highest (>0.07, >0.1, and >4) scores for the distance from the road, lineament, and fault are, respectively, (Fig. 3j–l). Road building activity in mountain areas is regarded as an infrastructure improvement that may be very detrimental to landslides. These lower scores suggest that the minimum distance from lineament, road, and fault makes the region more susceptible to landslides (Cao et al. 2021).

Rainfall is one of the significant triggering factors of landslides. Often, a heavy rainfall spell of 1 or 2 h can cause mass movement, or sometimes it can be an antecedent rainfall over the past few days (Dutta et al. 2021). The study area experiences an abundance of rainfall and recorded a value >1500 mm (Fig. 3m). The geomorphologic map depicts important geomorphic units, processes, landform, and structure that controls landslide. The geomorphological landforms are of eight categories: Terrace, WalBond-Pond, StrOri-Moderately Dissected Hills and Valleys, StrOri-Highly Dissected Hills and Valleys, Snow cover, WatBod-River, Valley, and Lake (Fig. 3n). Literature suggests that the dissected hills and valleys are more prone to landslides (Sonker et al. 2021). Most of the portion of this study area has moderately and highly dissected hills and valleys. It is recognized that geology is also one of the significant parameters that greatly influence landslide occurrence and lithological variation leads to a difference in the strength and permeability of rocks. Although lithology falls into three categories of geological age, i.e., Pleistocene, Mesoproterozoic, and Proterozoic periods (Fig. 3o), studies have suggested and was found that the Proterozoic age group in the Lesser Himalayan sequence is most prone to landslides (Tiwari et al. 2017).

4.2 Landslide Susceptibility Mapping

The various studies have been conducted and used weight combining methods for landslide susceptibility mapping (Abedini and Tulabi 2018). Identifying the landslide-prone area is not an easy task, as its mapping is very important for decision makers. The previously published researches have suggested that the AHP method is more suitable than the frequency ratio method. Therefore, in this study, a landslide susceptibility map was produced by combining all the influential factors according to weightage criteria using the AHP model (Table 3). Further, it was classified into low, medium, and high susceptible zones (Fig. 4). In light of the produced results, it was found that nearly 29% area of this region has been highly susceptible to landslides. The medium and low risks have shared 18 and 53% area, respectively, under the susceptible zones (Table 4).

The study area is undoubtedly not new to the phenomena of gravitational instability, as expected, the geologic setting and the characteristics of the terrains are a part of the Himalayas. Thus, the susceptibility to landslides is inbuilt in the natural characteristics of this landscape and there is a definite relationship between landslide occurrence and geophysical setup. Morphology of the hill slope has a great effect on the landslide events (Dai and Lee 2002). The Slope is considered as an important factor and the main reason for terrain instability (Haeri and Samiei 1996). In this study, high instability occurred in those regions where slopes were between 24° and 41°, whereas slopes less than 24° and higher than 41° angles were noticed to be less prone to landslide occurrences. Duration of rainfall and its intensity have a major role in the occurrence of landslides that, of course, depends on factors such as topography and geological structure of the slopes and their permeability (Lydia and Espizuajorge 2002). Heavy rainfall increases TWI, as well as STI, of a place due to water invasion in the gaps that leads to the slope deformation. The area where the values of STI, as well as TWI, were high has been found to be more susceptible to landslides. The instability is high in the valley area and along the roadsides. The city of Gangtok, which is the capital of Sikkim experiences great human interference and

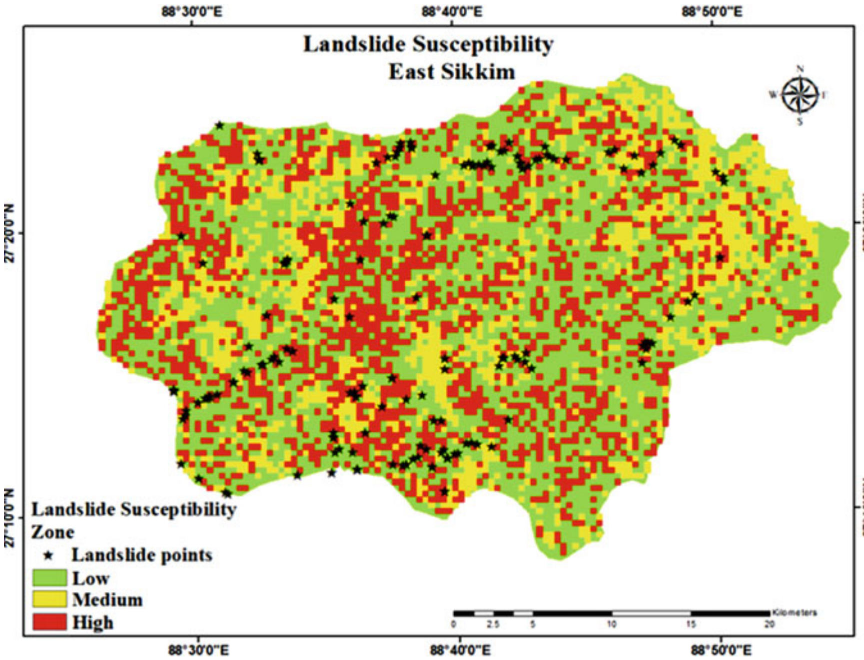

Fig. 4 Generated landslide susceptibility zones and overlaid point locations of past landslides

Table 4 Landslide susceptible zones with respective spatial coverage

Landslide susceptibility zone	Area in km^2	Area (%)
Low	510.42	52.948
Medium	165.54	17.172
High	288.04	29.88

goes through a phase of drastic development activities that ultimately influence the land cover and encroachments. This uncontrolled settlement and rampant expansion of roads and other land use practices encroached on the vulnerable land significantly increases not only the area under susceptible zones, but also the landslides frequency. The results showed that built-up areas, bare land areas, and agricultural field areas mostly fall into the high susceptibility zone. Road networking activity in mountain areas is regarded as an infrastructural enhancement, which may develop the ground for change in the stability of the landscape over there. The results reveal that the high susceptible zone is dominant along the roads and its periphery. The region is a part of an active continent–continent collision zone and the prime locations of all human activities enhance the risk potential of landslides. The area which lies within a 2 km buffer zone of the fault line falls under the high susceptible zone. Therefore, these all-important reasons are collaboratively responsible for landscape deformation.

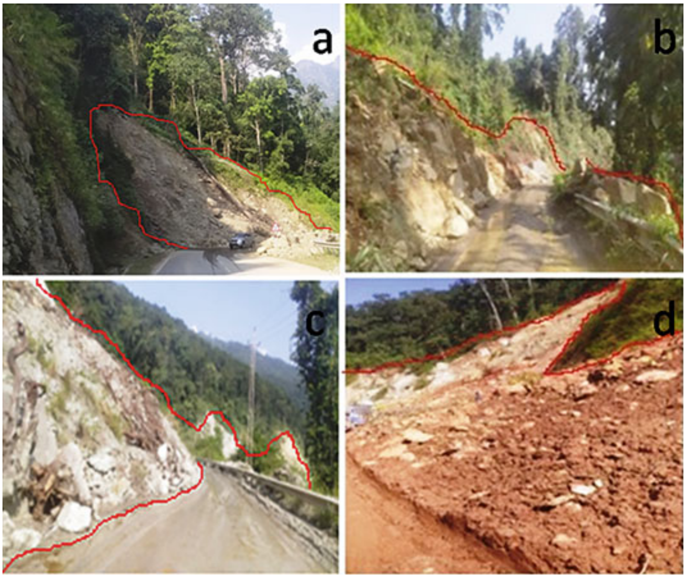

Fig. 5 Few samples of photographs of different types of slides. The Creep **a**, **b** Rockfall, **c** Debris flow cum rockfall, and **d** Debris flow pictures were taken during a field visit to validate the locations of landslides over susceptibility mapping

4.3 Landslide Inventories Validation Over Susceptibility Map

The landslide susceptibility map has been validated by superimposing the GSI landslide distribution point layer and supported by field photographs taken during the field visit (Figs. 4 and 5). According to GSI data, the study area had experienced approximately 167 landslides that differ in terms of width, length, and height. The overlaid analysis showed that most of the earlier landslides fall into the high susceptible zone followed by the medium and low susceptible zone. The different types of landslides photographs were also taken in the field in order to validate the present study (Fig. 5, panel a–d).

5 Conclusions

Disaster is a serious disruption that unstabilizes the general condition of the physical, social as well as economic environment. The young mountain region is more vulnerable to earthquakes and landslides. This study area is a part of the young folded mountain Himalaya, where landslide is a vast growing hazard that poses a great threat to human lives, properties, and rising infrastructure. Therefore, mapping landslide-susceptible zones is the first step to be taken as preventive measure. In this study, the AHP method has been used in the GIS environment by considering slope, LULC, NDVI, TWI, rainfall, Distance from (road, fault, and lineament), and elevation factors. AHP method is applied to assign the weight of each factor causing the landslide. Based on the AHP calculation, the four most influencing possible factors found for landslide occurrence are slope, rainfall, elevation, and TWI. The obtained susceptibility map and its related data show that the high susceptible zones cover an area of 29% followed by medium (17%) and low (53%) area. The map was validated by earlier landslides event data taken from GSI as well as supported with field photographs. However, the field visit was in the initial days to take an overview of the area, and the photographs taken for validation and to assess the types of slides are not sufficient enough to conclude the results very accurately in terms of field data. Although, landslide inventories dataset is highly recommendable to validate our landslide susceptibility mapping. This attempt would be helpful for planners and decision makers to follow the proper land use planning and slope management for sustainable development that could possibly minimize the upcoming landslide events in the study area.

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Socio-Economic and Ecological Vulnerability to Disasters

Socio-Environmental Vulnerability of Agriculture Communities to Climate Change in Western Himalaya: A Household-Level Review

Neha Chauhan, Henrik von Wehrden, and P. K. Joshi

Abstract Himalayan agriculture households face an increased risk of vulnerability due to its harsh intrinsic social and environmental factors. And the changing climatic conditions are further enhancing the vulnerability of these systems. To improve adaptation strategies and policy formulation, the impact of climate change on a household level needs to be accessed. However, comprehending the role of social and environmental factors in vulnerability assessments to climate change has received little attention on a household level. To integrate the knowledge available in the scientific literature, we performed a systematic review of peer-reviewed literature available on household vulnerability assessment (n = 21, focusing on research conducted in the Himalayas region). We evaluated the available literature according to (1) bibliometric features of selected studies and (2) the dynamic of vulnerability assessment. Most of the articles reviewed by us assessed vulnerability utilizing statistical assessment methods. The number of studies incorporating both social and environmental aspects has increased in recent years. Almost 50% of the studies focused on a single stressor, i.e., climate change for vulnerability. Holistic approaches and multi-level assessment are mostly lacking, as studied to combinedly assess both social and environmental factors.

Keywords Household vulnerability · Agriculture · Systematic review · Himalaya

1 Introduction

Global leaders, policymakers, scientists, and the common public are increasingly recognizing the impact of anthropogenic-induced global change that leads to local

N. Chauhan (✉) · P. K. Joshi
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India
e-mail: 92pneha@gmail.com

N. Chauhan · H. von Wehrden
Faculty of Sustainability, Leuphana University, 21335 Lüneburg, Germany

P. K. Joshi
Special Centre for Disaster Research, Jawaharlal Nehru University, New Delhi 110067, India

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environmental degradation, thereby putting people at risk (Schröter et al. 2005). The scale of threats ranges from global consequences such as temperature change due to greenhouse gas emissions, to localized impacts such as land degradation due to degrading agriculture practices (Devendra 2012). Dynamics among economic and social conditions might intensify or reduce the impacts of these changes (Ibarrarán et al. 2010). Nevertheless, the harm associated with global environmental changes has been on the rise for the past few decades (Fraser et al. 2011). To minimize the loss, concerning diverse dimensions of social, ecological, or financial factors due to these harms, we need to first accurately assess the *vulnerability* of varied systems surrounding us. Vulnerability assessments have emerged as a set of crucial tools to identify organizational shortcomings, which can weaken the performance of a system exploring the adaptation options available at hand (Füssel 2007), and identifying the hotspots requiring immediate assistance (Shukla et al. 2016). The vulnerable hotspots are rarely identified at different geographic scales (Brooks et al. 2003b), such as nations (De Souza et al. 2015), populations (Ibarrarán et al. 2010), communities (Chauhan et al. 2020a, b), or households (Gupta et al. 2020) to explore the drivers of vulnerability and suggest policy changes (Chauhan et al. 2020a; Mustafa et al. 2011). The hotspot identification at a local scale such as village and household level may help to identify tailormade adaptation actions and can thus allow for a better resource allocation (Wood et al. 2014).

Differences in vulnerability often depend on spatial and temporal variance (Fraser et al. 2011). High reliance on natural resources and choices for climate-dependent livelihoods, such as agriculture, makes societies more vulnerable to the impact of climate change (Aryal et al. 2014). Due to their high dependence on natural resources, the Himalayans and other socio-economically disadvantaged mountain areas are among the most vulnerable regions worldwide (Devkota et al. 2013; McDowell et al. 2013). For Himalayan communities, agriculture is the main source of livelihood as about 80% population of the Himalayas is directly or indirectly dependent on agriculture (Shukla et al. 2019; ICIMOD 2007).

The Himalayan agriculture communities are known to be highly susceptible to vulnerability (Ullah et al. 2018; Shukla et al. 2016; Panthi et al. 2016), due to intrinsic socio-environmental factors like the heterogeneous topography, rough terrain, remoteness, poor economic conditions, and fragility of Himalayan mountain systems. Other than above mentioned intrinsic factors, several extrinsic factors such as variable weather conditions, such as precipitation variability amplify the disproportionality in vulnerability for Himalayan agriculture communities. Hence, the increasing climate changes are severely impacting these communities (Joshi 2017; Gupta et al. 2019). The negative impacts of climate variability diversely affect Himalaya agriculture communities (Shekhar et al. 2010), increasing their vulnerability. To capture and monitor the complexity of vulnerabilities, several assessment methods have been developed and implemented at different spatial scales.

The rise in vulnerability among Himalayan communities underlines the need for spatially integrated vulnerability assessment to allow for location-specific adaptation strategies (Birkmann 2007; Eakin and Luers 2006). To improve local scale management of vulnerability and to allow the development of precise policies focused on adaptation strategies, a better understanding of social and environmental factors affecting the household vulnerability plays a decisive and urgent role (Ghimire et al. 2010). Agriculture households are facing distress by the unprecedented climate change impacts such as farm productivity deterioration, erratic rainfall and weather vagaries, decreased yield, and aggravating food insecurity (Shukla et al. 2019; Ahmad and Afzal 2019). Agrarian households in the Himalayas have in recent decades seen unparalleled transitions in social, environmental, and economic sectors (Devkota et al. 2013), with few positive and mostly negative effects on a household level (Ojha et al. 2015; Hahn et al. 2009). Given the challenges being faced by agrarian households, a critical evaluation of vulnerability assessments being performed is needed (Aryal et al. 2014; Ford and Smit 2004).

High variation among the driving factors of the household vulnerability suggests the requirement of diverse and multiple studies focused on their vulnerability assessment (Ullah et al. 2018). Despite the pressing need for such studies, the agrarian households of the Himalayas have been sidelined regarding fine-scale vulnerability assessment. In the plethora of vulnerability assessment studies, few studies to date focused on Himalayan households (Dialga et al. 2017). The present study aims to bring a comprehensive account of household vulnerability assessment with Himalayan-specific agrarian communities through a systematic review. We also examine the extent and nature to which these studies incorporate both social and environmental factors. The peer-reviewed studies are assessed broadly in three major steps, dividing our analysis into bibliometric analysis, methodological approaches of the reviewed studies, and the type and conceptualization of vulnerability assessed. Building on our review of the available literature, we will identify gaps and propose pathways for future research.

2 Methodology

To comprehend the current scientific literature focusing on agricultural households and their vulnerability to climate change within the Himalayas, a systematic literature review was conducted. Systematic literature reviews follow a well-defined procedure with a predefined set of inclusion criteria to extract and assess the existing knowledge from the available literature (Zhang et al. 2018).

2.1 Search Strategy

The peer-reviewed research articles involved in this systematic literature review were searched using the SCOPUS and the ISI Web of Science (WoS) database. Both the search engines provide an inclusive collection of existing literature across Himalaya covering the two major domains of vulnerability assessment, i.e., social and environmental sciences (Shukla et al. 2018), building on an extensive set of keywords. The majority of this research was performed from January to March 2020. English was the primary search language. WoS gave us 1799 number of hits, whereas SCOPUS provided us with 2288 research articles. A detailed description of our search keywords for literature is available in the supplementary file. After removing 2061 duplicates, a total of 2026 research articles remained. The following flowchart shows the procedure for finalizing the articles included in the study.

2.1.1 Inclusion Criteria and Article Screening

Research articles based on our search were sorted based on predefined inclusion criteria, based on our research focus. First, all the duplicates were removed, and a final set of articles were generated. Then based on the abstract, potentially applicable papers were evaluated. Finally, after abstract analysis, papers considered appropriate were processed via full-text screening (Fig. 1). At all stages of the screening process, the uncertain cases were subjected to a second opinion from fellow reviewers. Research articles with an unclear methodology for vulnerability assessment or operationalization were excluded, as well as studies based on local perception, adaptation strategies, livelihood and poverty issues, mitigation, and resource utilization with no relationship to the concept of vulnerability. The sequential screening of articles from the search performed finally led to the selection of a total of 21 articles dealing with the agriculture households and their vulnerability. The second reviewer also assessed all the articles recognized by the primary reviewer as possibly utilizable based on the full-text screening (Table 1).

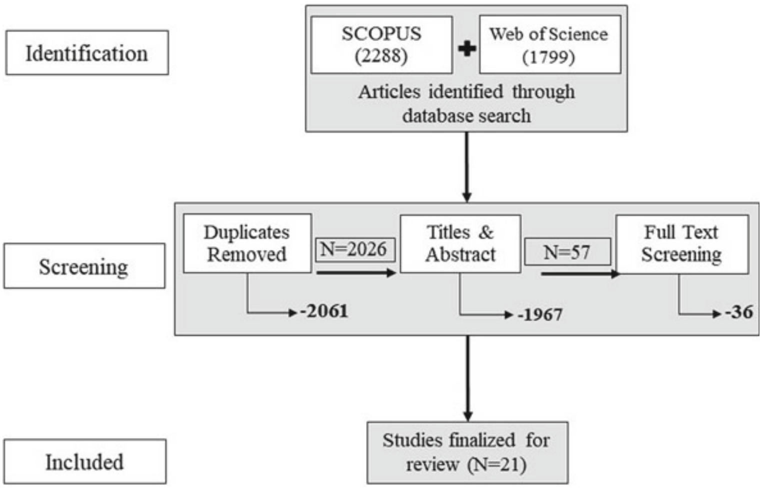

Fig. 1 The flowchart of article selection

Table 1 Criteria for inclusion of research articles in review

Criteria	Inclusion
Publication date	Articles published between January 2000 and October 2019
Document type	Peer-reviewed articles
Availability of article	Available on Web of Science (WoS) or Scopus
Theme of article	Articles assessing the vulnerability of agricultural households or farming households
Study area	Bhutan China (Tibet) Indian Himalayan region Nepal Pakistan

In the review process, the focus was to identify bibliometric characteristics (geographical scale of assessment and year of study/publication, stress under consideration) and dynamics of vulnerability (vulnerability-assessment approach, sub-dimensions, and indicators used to assess vulnerability, vulnerability framework, etc.) from the included studies.

2.1.2 Data Extraction

All included studies were subjected to content analysis. The studies were divided based on the initial question 'type of vulnerability assessment under consideration' and 'community in focus.' The major focus of the present study was to extract the present knowledge on agricultural households of the Himalayas. Consequently, the review process focused on critically analyzing the framework used for conceptualization of vulnerability and type of vulnerability assessed. The evolution of methodologies over the period in assessing vulnerability was also considered a major part of this review.

3 Results

3.1 Characteristics of Included Studies

Table 2 summarizes the characteristics of included studies. Among 21 studies selected, most studies were conducted in Nepal. Most of the studies focused on the assessment of the livelihood vulnerability of agriculture households. Climate change was the most widely studied stressor among these studies.

Table 2 Characteristics of the selected studies for review

Study objective	Study sites	Vulnerability assessed	HHs included	Data collection	Authors
Impact of climate and socio-economic change on the flexibility of transhumance communities	Solukhumbu, Dolakha, Bajhang (Nepal)	Livelihood vulnerability index and climate vulnerability index	145	Semi-structured interview	Aryal et al. (2014)
Determine the driving factors of farmland abandonment and understand the vulnerability of those farmlands	Nepal	Eco-environmental vulnerability	154	Structured questionnaire, FGDs, KII, secondary sources	Chaudhary et al. (2018)
Assess the sustainability of agriculture as a major livelihood option and its vulnerability	Mustang, Nepal	Livelihood vulnerability	3243	Secondary data	Chhetri (2006)
Analyzing food insecurity within the food system by applying concepts of vulnerability	Humla, Nepal	Food system vulnerability	313	Structured questionnaire, FGDs, KII	Gautam and Anderson (2017)
To identify the adaptation capacity methods by assessing vulnerability to climate change	Jumla, Nepal	Climate vulnerability and capacity analysis	483	PRA and secondary information	Gentle and Maraseni (2012)
Poverty and drivers of socio-economic disparity in HKH	HKH	Poverty index	141,978	Government resources	Gerlitz et al. (2012)
To devise adaptation strategies for farmlands vulnerable to droughts	Nepal	Drought vulnerability	158	PRA	Ghimire et al. (2010)
To examine the impact of an altitudinal gradient on the socio-environmental vulnerability of households	Garhwal, UK	Socio-environmental vulnerability	128	Questionnaire survey	Gupta et al. (2019)

(continued)

Table 2 (continued)

Study objective	Study sites	Vulnerability assessed	HHs included	Data collection	Authors
To gather knowledge pool for DRR by assessing the vulnerability of earthquake impacted households	Gorkha, Nepal	Disaster vulnerability	82	Interviews, participant observation	He et al. (2018)
Developing a vulnerability index for climate change and identifying suitable adaptation strategies	Uttarakhand, India	Climate vulnerability index	50	Questionnaire survey	Pandey and Jha (2012)
Index development to examine adaptation to climate change vulnerability	Dehradun, Pauri Gharwal (UK)	Adaptation capability index	120	Interviews and questionnaire survey	Pandey et al. (2016)
To identify the potential adaptation responses to climate change	Pauri Garhwal, UK	Climate vulnerability index and current adaptive capacity index	50	Questionnaire survey	Pandey et al. (2017)
To assess the food security of the river basin	Nepal	Household food insecurity access scale	360	Interviews	Pandey and Bardsley (2019)
To develop site-specific intervention techniques for vulnerability reduction	Gandaki, Nepal	Livelihood vulnerability index	543	Household survey and secondary data	Panthi et al. (2015)
Perception of rural population to the impact of climate change on food insecurity	Lamjung, Nepal	Food insecurity	150	PRA, FGDs, KII	Poudel et al. (2017)
Vulnerability of watershed HHs to hazards	Himachal Pradesh, India	Hazard vulnerability	200	Questionnaire survey and satellite imagery	Prasad et al. (2016)
The paper intended to highlight the variation in vulnerability due to site-specific differences	Faisalabad, Khan, Mardan (Pakistan)	Livelihood vulnerability index	150	Household surveys	Qaisrani et al. (2018)

(continued)

Table 2 (continued)

Study objective	Study sites	Vulnerability assessed	HHs included	Data collection	Authors
Impact of vulnerability on livelihood, poverty and other social and environmental aspects	Khyber Pakhtunkhwa, Pakistan	Vulnerability index	200	FGDs, KII, household survey	Shahzad et al. (2019)
Increase the understanding of vulnerability to livelihood at the household level	Melamachi, Nepal	Livelihood vulnerability index	365	Household survey and secondary data	Sujakhu et al. (2019)
To understand the impact of socio-economic conditions on agroforestry as a livelihood option	Himachal Pradesh, India	Social and livelihood vulnerability	180	Interviews	Tiwari et al. (2018)
To collect farm-level evidence and highlight the climate change vulnerability	Khyber Pakhtunkhwa, Pakistan	Climate change vulnerability	116	Household surveys	Ullah et al. (2018)

FGDs: Focus Group Discussion; HHs: Households; KII: Key Informant Interviews; PRA: Participatory Rural Appraisal

3.2 Bibliometric Analysis

The study is distributed among the five countries, i.e., India, Nepal, Bhutan, China (part of Tibet), and Pakistan, which are a part of the Himalayas. Vulnerability assessment is one of the latest explored concepts to comprehend the impact of changing climatic and environmental scenarios on agriculture communities (Shukla et al. 2017). Most studies focusing on agricultural households were conducted rather recently (see Fig. 2). More than 60% of the studies were published between the years 2016 and 2019. This recent increase in the quantity of publications assessing the vulnerability of agricultural households is a result of the enhanced demand for evidence required for policy formulation regarding adaptation strategies among these agricultural communities (Ojha et al. 2015).

Nepal has the highest number of studies (11 papers) focusing on agriculture household level multi-scale vulnerability assessment, followed by India (6 papers). Pakistan has a total of three household-level assessments whereas no studies focusing on a household level were conducted in China and Bhutan. However, one study spans across the whole Himalayas considering all five nations. Figure 3 shows the distribution of country-wise sites in different studies.

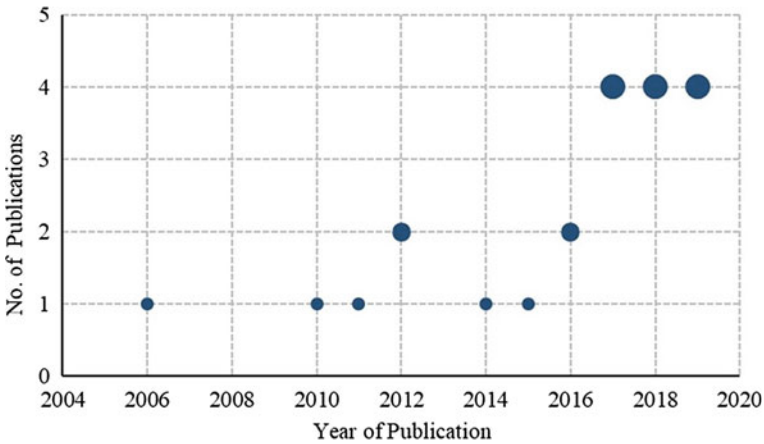

Fig. 2 Yearly distribution of agriculture HHs vulnerability assessment-based publication

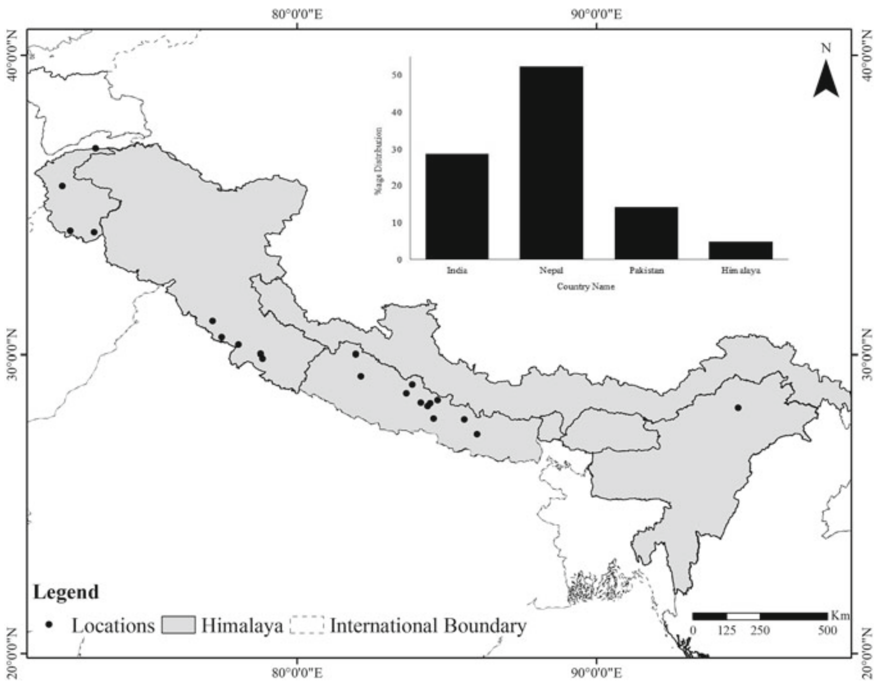

Fig. 3 Map showing the country-wise distribution of studies in the Himalayas

The difference in geographical scale for household selection varied at a wide scale. In the selected studies, households were investigated at administrative and biophysical scales or both. Most of the studies (33%) were performed at the district level. The household selection at the village level was done in 24% of studies. Country, village council (Panchayat), and township (tehsil) were the preferred geographical levels to select households in 5% of studies each. Among the physical scale, 9% of studies chose watershed and altitudinal zonation for household selections. Only two studies chose households with mixed administrative and physical scales.

3.3 Methodological Approach

The methodological approaches can be broadly divided into three major types, based on the methods and techniques applied to collect the data, namely (a) quantitative approach, (b) qualitative approach, and (c) mixed methods (Creswell 2014). Table 2 shows the methods used for data collection by respective studies. For data collection, most studies have employed a mixed-method approach (57%), participatory rural appraisal techniques such as focus group discussions (FGDs), semi-structured interviews, and key informant interviews (KII). The rest of the studies, i.e., 43% have used quantitative methods for data collection such as questionnaires, spatial analysis, ecological surveys, secondary government data, etc.

For vulnerability assessment and interpretation of data, three major approaches were utilized: (a) qualitative approach (QA), (b) indicator-based approach (IBA), and (c) statistical analysis (SA). Table 4 shows the type of methodological approach implemented by the articles selected for this review. Most of the studies (48%) employed the SA method for data analysis and interpretation. The IBA method was used by 38% of the studies for vulnerability assessment, whereas the QA method was used by only 14% of studies. The results are clear indicators of the greater use of statistical analysis in the vulnerability assessment of agriculture communities. Multivariate statistical analysis (such as principal component analysis (PCA) and multivariate logistic regression (MLR)) was performed for vulnerability assessment, and in some cases, qualitative vulnerability assessment and participatory rural appraisal (PRA) (such as FGDs, KII, etc.) were performed.

3.4 Dynamics of Vulnerability

3.4.1 Conceptualization of Vulnerability

Scholars from different academic or knowledge domains have a different understanding of the term vulnerability, making vulnerability a very complex and deeply contested subject, spread across various conceptual frameworks implemented in

Table 3 Percentage distribution of vulnerability frameworks applied

Framework	Components	% studies (N)
IPCC (TAR, AR4)	*f* (Adaptive capacity, sensitivity, exposure) *f* (Adaptive capacity, sensitivity)	38 (8)
Sendai framework	*f* (Disaster)	4.75 (1)
FAO food insecurity scale	*f* (Food availability, health and hygiene)	4.75 (1)
Differential vulnerability		9.5 (1)
LVI-IPCC	*f* (Social networking, livelihood opportunities, demographics, climate variability and disasters)	19 (5)

IPCC = Intergovernmental Panel for Climate Change; TAR = Third Assessment Report; AR4 = Assessment Report 4; FAO = Food and Agriculture Organization; LVI = Livelihood Vulnerability Index

comprehending vulnerability. The studies included in the review have conceptualized vulnerability based on different frameworks. Table 3 lists various frameworks, their essential component, and their usage in different studies.

The conceptualization differs in the presumed centrality of the socio-economic status of households, which plays a major role in deciding adaptation strategies implemented by households to dampen the effects of vulnerability. Eight studies use different frameworks by IPCC. The third and fourth IPCC assessment reports identify vulnerability as a function of exposure to external stressors, the sensitivity of the system and communities, and its tendency to adapt to the stressors while the fifth IPCC assessment report considers vulnerability to be entirely a function of inherent factors responsible for its sensitivity and intrinsic adaptive capacity (IPCC (2007, 2014)). The Livelihood Vulnerability Index framework, also implemented by Hahn et al. (2009), Schröter et al. (2005) and Brooks (2003a), was used in four studies. This framework conceptualizes vulnerability as a major function of livelihood options and natural hazards.

Conceptualizing vulnerability based on the social and economic construct of the household was done by two studies. Sendai framework (developed by UNISDR—the secretariat for the International Strategy for Disaster Reduction, now known as United Nations Office for Disaster Risk Reduction (UNDRR)), conceptualizing vulnerability based on disaster occurrence, frequency, and magnitude, was used in one study. The Sendai framework is a major reference used in disaster studies or vulnerability assessment of hazards. Household Food Insecurity Access Scale, developed by FAO, was used in a study to conceptualize vulnerability. Many articles (at least five studies) did not specify the framework used by them to conceptualize vulnerability in their studies. Table 4 shows the vulnerability framework distribution in respective studies.

3.4.2 Deliberated Stressors of Vulnerability

The impact of changing climate on agriculture communities has been the topic of great concern at various geographical levels, be it at global, national, sub-national,

Table 4 Distribution of vulnerability in respective studies

Methodological approach	Vulnerability framework	Authors
Index-based approach	IPCC TAR AR4	Aryal et al. (2014)
Statistical approach	Do not specify any conceptual framework	Chaudhary et al. (2018)
Statistical approach	LVI-IPCC	Chhetri (2006)
Statistical approach	Do not specify any conceptual framework	Gautam and Andersen (2017)
Qualitative approach	Differential vulnerability	Gentle and Maraseni (2012)
Statistical approach	Differential vulnerability	Gerlitz et al. (2012)
Statistical approach	IPCC TAR AR4	Ghimire et al. (2010)
Index-based approach	IPCC TAR AR4	Gupta et al. (2019)
Qualitative approach	Sendai framework and IPCC TAR AR4	He et al. (2018)
Index-based approach	IPCC TAR AR4	Pandey and Jha (2012)
Index-based approach	Do not specify any conceptual framework	Pandey et al. (2016)
Index-based approach	IPCC TAR AR4	Pandey et al. (2017)
Qualitative approach	FAO Food Insecurity Scale	Pandey and Bardsley (2019)
Index-based approach	LVI-IPCC	Panthi et al. (2015)
Statistical approach	IPCC TAR AR4	Poudel et al. (2017)
Statistical approach	Do not specify any conceptual framework	Prasad et al. (2016)
Index-based approach	LVI-IPCC	Qaisrani et al. (2018)

(continued)

Table 4 (continued)

Methodological approach	Vulnerability framework	Authors
Statistical approach	IPCC AR5	Shahzad et al. (2019)
Index-based approach	LVI-IPCC	Sujakhu et al. (2019)
Statistical approach	Do not specify any conceptual framework	Tiwari et al. (2018)
Statistical approach	IPCC TAR	Ullah et al. (2017)

IPCC = Intergovernmental Panel for Climate Change; TAR = Third Assessment Report; AR4 = Assessment Report 4; LVI = Livelihood Vulnerability Index

or regional levels (Shukla et al. 2017). While the primary concern of national and sub-national levels was long-term meteorological changes, the regional level was the major focus regarding people's perception of climate change. This high significance of climate-related risks for agriculture communities was investigated by studies focusing on the local level as well. Out of the total studies selected for this review, almost half studied the vulnerability of agriculture households to climate change. The studies considered the perception of communities toward climate change and the impact of changing temperature and rainfall on agriculture and its productivity.

19% of the studies assessed the vulnerability of agriculture communities to changing socio-environmental conditions such as decreasing fertility of farmland, altitudinal gradient, varying resource availability, etc. (Shahzad et al. 2019; Gupta et al. 2019; Chaudhary et al. 2018; Chhetri 2006). Hazard occurrence and susceptibility was the central concern of three studies out of the total selected. Earthquakes, drought, and flash floods were the major hazards discussed. The past few decades have witnessed an increase in socio-economic disparity. The increased socio-economic inequality has led to an uneven distribution of resources among the population. Two papers (Tiwari et al. 2018; Gerlitz et al. 2012) analyzed the impact of changing socio-economic conditions on the vulnerability of agrarian households. Food insecurity also acts as a stressor of vulnerability. Two papers (Pandey and Bardsley 2019; Gautam and Andersen 2017) used food insecurity to identify the vulnerable households of the Himalayas.

Regarding vulnerability indicators at the household level, the Livelihood Vulnerability Index (LVI) by IPCC was the most widely considered. This index incorporates both social and environmental indicators to understand how the change in these variables impacts the livelihood of households (Prasad et al. 2016; Panthi et al. 2015). The livelihood opportunities at a household's disposal can be the most efficient adaptation strategy against vulnerability. Developing rural livelihood through increasing assets is a major adaptation policy in developing nations. Other types of vulnerability considered in the selected studies are mentioned in Table 2.

3.4.3 Components of Vulnerability Addressed

Vulnerability assessment is a complicated and multi-dimensional concept due to its dynamic nature. It incorporates a varied number and types of parameters ranging from social, financial, human, natural, environmental, and other aspects. The coupled human–environmental systems of agriculture communities' experiences impact all the above factors, thus highlighting the importance of identifying their role in vulnerability. The selected studies for review have identified various indicators to represent the different aspects of vulnerability assessment.

The indicator selection is dependent on multiple factors such as the type of the methodology utilized for vulnerability assessment, the object of assessment, data availability, etc. The IPCC approach to vulnerability assessment is the most widely used framework for indicator selection. The IPCC takes vulnerability as a function of adaptive capacity and sensitivity. In all the studies following this method (8 in total), the authors used the hierarchical method to divide the three major components (sensitivity, adaptive capacity, and exposure) into sub-components and then indicators. Table 5 shows the selection of the component, sub-components, and prominent indicators used by authors performing the index-based assessment:

The ability to cope with the vulnerability after certain readjustments in socio-economic systems is known as adaptive capacity. To frame appropriate policies to tackle the problem at hand, it is necessary to understand the profile of households. The understanding of the condition of assets available at the households' disposal be it financial, social, or human is required in making adaptation decisions, efficient resource allocation, and mitigating strategies.

Climate variability and natural disaster were the sub-components used to capture exposure (Table 5). Temperature fluctuations, erratic precipitation patterns, and climatic extreme events are identified as the major variables affecting the primary livelihood (agriculture) of Himalayan communities (McDowell et al. 2013; Panthi

Table 5 Distribution of indicators used among the studies

Components	Sub-components	Number of articles
Adaptive capacity	Socio-demographic characters (*household profile, education, information*) Livelihood diversification (*variation in employment options*) Social networks (*community support*, *involvement in social gatherings*, *assets*)	8
Exposure	Climate variability (*temperature, precipitation*) Natural disasters (*floods, landslides, other disasters*)	7
Sensitivity	Water (*irrigation facilities, drinking water, water quality*) Health (*medical facilities, nearness to health centres*) Food (*food insecurity, access to food, food availability*) Finance (*access to banking, loans, mechanization*)	7

et al. 2015; Sujakhu et al. 2019). Also, natural hazards such as landslides, flash floods, cloud bursts, and drought have devastating impacts on the inherent climate-sensitive livelihood ranging from changes in the sowing season to wiping off the standing crop (Pandey and Jha 2012; Qaisrani et al. 2018). Changing climate is having visible effects on the hydrological cycle of the Himalayas, leading to decreased water availability at the right time and generating water stress (Kelkar et al. 2008; Gerlitz et al. 2017; Gupta et al. 2019). Water scarcity has led to decreased options for irrigation facilities in the Himalayas, leading to decreased agricultural production due to water stress (Xu et al. 2009).

Agriculture in the Himalayas is extremely sensitive, due to its high dependence on natural resources, limited possibilities of mechanization, rough terrain, etc. The farmers are mostly smallholders practising agriculture mostly dependent on rainfall for irrigation, adding up to the sensitivity of their livelihood. Poor institutionalization, lack of infrastructure, and limited access to knowledge are other factors that are increasing the sensitivity of Himalayan agriculture communities.

The diversity in agriculture communities of the Himalayas broadens the number of indicators acting as a proxy of sensitivity, adaptive capacity, and exposure (Shukla et al. 2016). The following were the most repetitively used indicators to assess the vulnerability of agrarian households in the Himalayas by selected studies: demography, social, demography, livelihood, employment, climate and climatic hazards, institutional networks, finance, health, livestock, food insecurity, water unavailability, income, migration, irrigation, and education.

4 Discussion

This review intended to understand the state of the ongoing research on the contribution of social and environmental factors to the vulnerability of households of the Himalayas and comprehension of the impact of climate change by the research community. The existing literature has established the necessity of the socio-environmental vulnerability assessment on a household to ameliorate the prevailing adaptation strategies or suggest newer coping actions. A total of 21 studies were reviewed to document the household vulnerability and drawbacks in the current assessment. The review was able to identify the gaps existing in the research and provide suggestions for a way forward.

4.1 Limitations of Reviewed Studies

This review found two major limitations in the conception and operationalization of vulnerability assessment in the selected studies. First, the studies provide varied understandings of vulnerability assessment, a diverse number of stressors driving vulnerability, and the procedure of indicator selection was the most crucial and most complicated. The dynamic nature of the world of Himalayan agricultural communities and their vulnerability makes the indicator selection spread into the realms of social, environmental, political, and economic factors consistently varying over time (Soubry et al. 2020). Despite the in-depth literature review, regardless of the method employed in assessment, the selection of appropriate indicators properly representing these factors is subject to uncertainties which make the final scores, and results vacillate (Dialga et al. 2017). The coupled human-environmental nature of the agriculture system in the Himalayas either gets enabled or is constrained by different factors and thus requires a balanced integration of the two (Pandey and Bardsley 2019). However, based on the review very few studies offer an integrated investigation of both social and environmental factors. This might be due to the inaccessibility of data for the Himalayan region.

The importance of social and environmental indicators in shaping our final vulnerability score is usually determined by the weights allocated to the indicators. Challenges prevail not only when these indicators are selected, but also when weights are assigned to these indicators. The major disadvantage of this procedure is that the value of indicators varies not only from community to community but also from household to household depending on the predisposed conditions of a specific household (Yoon 2012; Hinkel 2011). At some point in the identification and weighting of measures, subjectivity on the part of the author comes into play and can affect the final scores (Etwire et al. 2013). There often exists a non-linearity in the factors affecting the vulnerability of any system, but while assessing it, the indicators are often treated in a linear manner dissolving all the inter-connections of factors and indicators (Tonmoy et al. 2014). Addressing the matter of indicator selection, weights distribution, and nature of subjectivity in this process is critical while framing the methodology of vulnerability assessment and extracting knowledge for adaptation strategies.

The second limitation of the reviewed studies is data collection. The primary research focused on households and the key source of knowledge was surveys, questionnaires, interviews, etc. This approach relies heavily on the responses given by the group or household members. The knowledge collected depends on the person's understanding of filling out the forms or being interviewed (Queirós et al. 2017). Also, the reliability of these methods of data collection is highly dependent on the structure of the questionnaire or interview and the accuracy in the interpretation of responses being provided to the interviewer. Bias in data collection is often rooted in sampling by the dominant of elite or exclusion of less privileged sections of society (Razavi 2001). Replication of study becomes difficult in this scenario, as it is arduous to control the variables and environment affecting the subjects or participants.

4.2 Holistic Approach Toward Multi-stressor Studies

Mountain socio-ecological systems, such as agriculture, are highly sensitive to changes in climatic conditions and are prone to the impact of various socio-economic agents (Sharma et al. 2017; Archer 2016). Due to the unknown nature of magnitude or impacts of climatic changes, such changes are known as 'novel changes.' Whereas the socio-economic changes affecting the agricultural communities are called 'direct changes' (Cifdaloz et al. 2010). Despite the differences in the impacts of both types of changes, there is a complex inter-connection between climatic and other changes (Räsänen et al. 2016). Neither the climatic factors nor the socio-economic factors can be studied in isolation, as socio-economic stressors shape the context in which impacts of climate change are perceived and vice versa (O'Brien et al. 2004).

Many researchers have acknowledged the need for a holistic approach to identifying the inter-connections between 'multiple stressors of vulnerability' (Shukla et al. 2017; Räsänen et al. 2016; O'Brien et al. 2009). Few of the selected studies incorporated both type of stressors but failed to acknowledge the underlying interconnections. None of the studies included unequivocal analysis of interactions. The lack of an explicit analysis of the interaction between different stressors might lead to diminishing the relative importance and impacts of these stressors and may make the assessment biased. Consequently, it is vital to recognizing the causal–response relationship between climatic and non-climatic stressors instead of dividing them into groups and looking at them individually.

4.3 Exposure Dynamics

The report on climate-change-related events and disasters (IPCC 2012) identifies exposure as:

> … the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage. (IPCC 2012, 32).

The physical events mentioned above might be natural disasters or climatic variability making the communities, populations and households exposed to vulnerability. To develop strategic adaptation plans for mitigation against vulnerability, it is vital to recognize the most exposed populations. However, the review highlighted the lack of focus given to exposure factors and their identification. The majority of the studies treated perception of the common public as proxies to quantify the extent to which a particular system is exposed. The indicators selected were concentrated on perceived changes in temperature, precipitation, dry spells, or cold weather. To date, no study utilized meteorological datasets to identify the extent of change in climatic conditions in the Himalayas, probable dues to a general lack of available datasets.

Another drawback, which became apparent through our review, was the lack of studies incorporating future projections when it comes to exposure. The impacts of changing climate are often displayed through erratic flooding and precipitation, changed the regime of droughts and variation in the frequency of extreme events. These events hamper the developmental projects and create enormous economic and social challenges for developing countries (Morgan 2011). To lessen the threat posed to developmental activities, it is essential to use future projections in the assessment of vulnerability and identification of change of shift drivers of vulnerable hotspots (Jurgilevich et al. 2017).

4.4 Governance Capacity and Policy Capability

In order to improve policies, studies of governance need to comprise all the different actors under one umbrella. Another point to improve governance is identifying the geographical location and understanding the physiography of the location. When it comes to vulnerability, for the identification of the most urgent and pressing adaptation needs, the policymakers and planners require to assess the main actors with responsibility, the required scale of policy implementation, and the appropriate approach to action (Keskitalo 2009). Few of the studies selected for the present review investigated governance. The outcomes of these studies presented the development planners and policymakers with statistically results with real-time implementation. The studies provided solutions to bridge the gap between policymaking at the macro-level and household necessities and urgencies at the micro-levels. The point that higher-level adaptation policy formulation and planning development must involve the local-level requirements and information, forming multi-level governance, draws emphasis on such micro-level studies (Hooghe and Marks 2003). Most of the indices generated might be useful in providing recommendations for setting priorities for action, developing an integrated and robust model for resilience to climate change at various levels, and assessing the impacts of ongoing policies. The studies can also help with assessing future vulnerability and risk scenarios in case of some policy interventions to calculate the success of a given policy. The practicality of the final outcomes of the studies in the understanding contribution of different factors/indicators such as climate, demography, finance, etc. to vulnerability provides a flexible approach to development planning and establishes the importance of local level and focused studies in the field of vulnerability assessment.

5 Conclusion

We reviewed published studies concentrating on the vulnerability of Himalayan agriculture households. Our review highlights the need of centering households within adaptation policy deliberations regarding the vulnerability of agriculture systems. Our review underlines that while formal household vulnerability assessment attempts have been made but in limited numbers. The results of the studies are limited by the availability of data, subjective nature of indicator selection and weightage, and methodology of data collection. Data integration between different data collection techniques such as participatory rural appraisal, focus group discussions, remote sensing, and national and international records are widely lacking in data. Diversity in the nature of stressors often gets sidelined due to the scarcity of data for the Himalayan region. The need for an integrated vulnerability assessment is attempted by few studies, but for an in-depth understanding of inter-connections between various stressors, more studies are required. Also, the higher dependency of researchers on perception-based climate change assessment needs to be addressed immediately and more options for meteorological data availability should be provided. In order to acknowledge the complicated nature of vulnerability in mountains, which is affected by social, environmental, economic, and political issues along with climatic variability, adopting a multiple stressors approach is necessary. Studies utilizing such an approach obviously play a large role in strengthening the governance by providing suggestions for policy formulation and implementation. In addition, more emphasis on direct policy orientation would increase the recognition of the importance of such approaches. Integrating a more holistic quantitative approach in the household level assessment of vulnerability, as well as integrating risk management and climate adaptation may serve as a basis to approach the problems of global change on a household level in the Himalayas.

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Application of Mike 11 for One-Dimensional GLOF Modeling of a Rapidly Expanding Dalung Proglacial Lake, Indus River Basin, Western Himalaya

Riyaz Ahmad Mir, Sanjay K. Jain, A. K. Lohani, Rayees Ahmed, Syed Towseef Ahmad, and Gowhar Farooq Wani

Abstract In the Himalayan region, majority of the proglacial lakes formed behind the poorly sorted and loosely unconsolidated end-moraine dams are expanding rapidly owing to the rapid recession and thinning of its mother glaciers in response to climate change. These lakes consist of inherently unstable glacial material having a huge potential to burst and give rise to worse scenarios of Glacial Lake Outburst Floods (GLOFs) and hazards. Here, the dynamics of Dalung Proglacial Lake (DPL) located in Suru catchment of Zanskar River, Indus River Basin, Western Himalaya has been evaluated using the SoI maps (1962), Landsat TM (1990) & ETM + (2000), IRS LISS-III (2005), Google Earth TM (2015), and ASTER GDEM. MIKE 11 was employed for one-dimensional hydrodynamic modeling of GLOFs of the DPL at the lake site and downstream site. The DPL has developed at the snout of Dalung Glacier (DG) probably during the last five decades (1962–2015) in response to its recession by 1.240 km (15.7%) at a rate of 20 ma^{-1}. From 1990 (0.20 km^2) to 2015 (0.48 km^2), DPL has expanded rapidly by 0.28 km^2 (58%) at a rate 0.011 km^2a^{-1}. The DPL has been characterized as a potentially dangerous lake based on the type of lake and its volume, rate of lake formation and growth, position of lake, dam condition, conditions of associated mother glacier, morphometric characteristics of glacier, physical conditions of the surrounding area and situation down the valley. A flood peak discharge (GLOF) of 3361.7 m^3 $s^{-1}$was estimated at lake site which was later reduced to 1520.9 m^3 s^{-1} at the downstream outlet site after traveling a distance of 34 km. The flood peak discharge has a immense potential to create hazardous GLOF event, and therefore, a detailed field investigation and regular monitoring of the lake is recommended.

R. A. Mir (✉)
Geological Survey of India, Srinagar, UT: Jammu and Kashmir 190008, India
e-mail: riyazgsi@gmail.com

S. K. Jain · A. K. Lohani
Water Resource System Division, National Institute of Hydrology, Roorkee 247667, India

R. Ahmed · S. T. Ahmad · G. F. Wani
Department of Geography and Disaster Management, University of Kashmir, Srinagar 190006, India

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1 Introduction

Glaciers all over the world are receding and thinning at a remarkable pace in response to the changing climatic regimes (Bajracharya et al. 2008; Mir et al. 2013, 2014a, 2015a, 2017; Cogley 2016). Himalayan glaciers, in particular, are shrinking extensively and tremendous mass loss has been observed, which clearly depicts the significant decline in glacier length (Sakai & Fujita 2017; Majeed et al. 2020; Mir et al., 2014a, b; Mir and Majeed 2018; Ahmed et al. 2021a; Mir 2021). Continuous recession and thinning of the glaciers in response to climate change have given rise to a large number of glacial lakes in the Himalayan region (Yao et al. 2012; Mir 2018; Ahmed et al. 2021b). These glacial lakes are generally formed behind the unconsolidated and unstable glacial end moraines deposits (Kaser et al. 2006; Bolch et al. 2012; Mir et al. 2015a, b, c). Moraine dammed glacial lakes have higher tendency of breaching and therefore could be potentially dangerous due to the accumulation of large volumes of water. During any type of breaching and rapid discharge of water and debris from such types of lakes huge outburst floods (GLOF) and hazards can be produced in downstream areas (Benn et al. 2012; Westoby et al. 2014; Worni et al. 2014). During the recent past, glacial lakes are found to be expanding very rapidly in response to climate change (Reynolds 2000; Benn et al. 2012; Jain & Mir 2019; Ahmed et al. 2021c). Nevertheless, due to frequent GLOF events witnessed in the Himalayan region, the risks to livelihood and other infrastructure have also grown up in the downstream areas of prone glacial lakes.

For the assessment of the GLOF hazards in any region, the mapping and identification of potentially dangerous glacial lakes is very imperative. For this purpose, the Geographic Information System (GIS) and Remote Sensing (RS) technology has been successfully used globally. The GIS and RS-based techniques allow rapid analysis of large glaciated areas in a very inexpensive way and are therefore considered very suitable for glacial lake and GLOF studies (Huggel et al. 2002; Kääb et al. 2005). Similarly, the flood water movement through any natural landscape resulting due to the failure of the dam can be predicted using various kinds of methods. Glacial lake dam breach and its subsequent flood events can pose a serious threat to the people and infrastructure downstream (Jain et al. 2012; Mir et al. 2018). Since, such events are largely very uncertain; thus, they can breach unexpectedly without any warning. Additionally, the Humans can't prevent or stop occurance of such type of catastrophic events but, a precise assessment and subsequent modeling to predict such events, its hazards and flood water movement can be done using geospatial techniques (Huggel et al. 2002; Jain et al. 2012; Mir et al. 2018). Although modeling can't be properly accurate, still they can provide us a better idea of the extent up to which flood water gets inundated at the time of Dam-Break event and to understand its associated hazards. For the purpose of dam break flood simulation and GLOF studies, scaled physical hydraulic and mathematical simulation models are very frequently used generally (WECS 1987; Bajracharya et al. 2007).

In this study, the temporal dynamics of Dalung Glacier (DG) and its Dalung Proglacial Lake (DPL) located in Suru catchment of Zanskar River, Indus River Basin, located in Western Himalaya has been evaluated using satellite and other ancillary data sources. Furthermore, the Mike 11 model has been applied for one-dimensional hydrodynamic flood modeling of DPL.

2 Study Area

The DPL is located in the sub-catchment of the Suru River basin of Zanskar River, Indus River Basin, located in Western Himalaya. The total area of the catchment is 39 km^2. It contributes its discharge to the Suru River which flows in the northwest direction before joining with the Indus River. The DG and DPL emerge from the Greater Himalayan peaks located in northwest of Pensi La. The stream emerging from DG and PDL initially flows towards the eastern direction before joining with the Suru River flowing in northeast to northwest direction. The DPL is spread between the geographical coordinates of N33° 56′22″ and E76 13′43, in the area (Fig. 1). The snout of the DG observed during 2015 was located at an altitude of 4031 m a.m.s.l. The mass accumulation of snow feeding and contributing to the glaciers of Zanskar

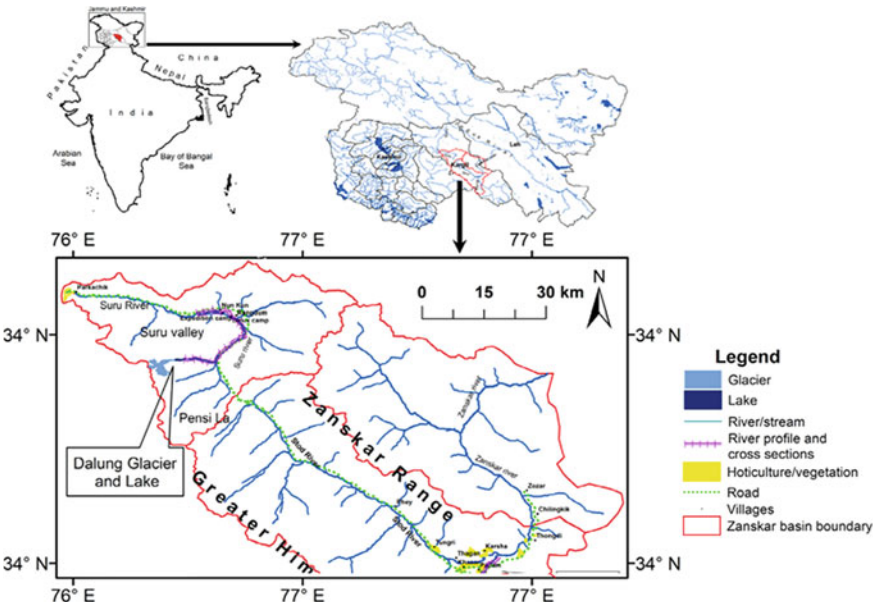

Fig. 1 Location map of the study area including DG and DPL

Basin including DG occurs generally through direct snowfall, as well as through the blowing snow and avalanches in the area. In this study, the dynamics of the Dg and DPL was studied extensively. It is because, previously, Worni et al. (2012) have classified the DPL as potentially critical and recommended a regular monitoring and possibly field reconnoiter survey of the lake.

3 Data and Methods

In the present investigation, we used the Survey of India (SoI) toposheets on 1:50,000 scale and Landsat satellite data sets of MSS (57 m), ETM + /TM (30 m) and IRS-P6-LISS-III for identifying and spatio-temporal mapping of the DG and DPL in the area. For recent time period, the glacier and its associated lake were mapped using the Google Earth in 2015. The year 2015 acted as the recent source of information about the dimensions of the lake. A detailed investigation on the dynamics and GLOFs of the DG and DPL has been carried out using the satellite data sources. The details of satellite data used are included in Table 1. The closest scenes available for any of the years were used jointly to map the glacier as well as the lake accurately. The ASTER-GDEM available from USGS was used as a reference GDEM in this study. The DEM was used for semi-automatic extraction of drainage basins and estimation of other topographic parameters. The watershed/catchment of the glacier and its lake were also derived from ASTER-GDEM. The cross-section at a regular interval of 1 km along with other details of elevation were also obtained from the ASTER-GDEM. The cross sections were generated downstream from the lake to the last selected downstream site in GIS platform. The cross sections from the DEM

Table 1 Data used for the study area

Map & image/sensor type (Resolution m)	Acquisition date	Source
Topographic map	1962	SoI
MSS (57)	10/11/1975	GLCF/NASA
TM (30)	09/10/1989	do
	29/07/1990	do
ETM + (30, 27)	22/10/2000	do
	29/09/2000	do
	02/09/2005	USGS/NASA
	20/10/2005	do
LISS-III (23.5)	29/10/2005	NRSC/ISRO
TM (30)	28/08/2009	USGS/NASA
	02/10/2010	do
GEOEYE (4)	5/02/2015	Google Earth
ASTER GDEM (30)	2015	NASA

were generated because the field measured cross sections were not available for this area. For the purpose of identifying whether the lake is potentially dangerous, an integrated latest criterion developed from recent literature was used in this study. It was followed by the application of one-dimensional MIKE 11 model for simulation of the GLOFs as well as to assess the relevant hazard potential of the lake to the downstream areas. Details of the methodology and accuracy assessment of the glacial lake mapping and model inputs used in this study are discussed in detail by Mir et al. (2018).

4 Results and Discussion

4.1 Characteristics of DG and DPL

The detailed characteristics of DG and DPL are given in (Table 2). The DG and DPL were visibly covered on images acquired during 1990 and 2009. However, towards the northern part of the study area, the DG and DPL were not visible clearly due to the presence of snow cover present on either of the satellite images of 1989 and 2010. Therefore, in the present study, the years 1990 and 2009 were considered representative for further systematic analysis and comparative study to understand the temporal changes of the lake as well as its mother glacier. Furthermore, before the time period of 1990, the information about the presence of the DPL is not well documented because of non-availability of the appropriate datasets for the area. Additionally, the changes 1989–1990 and 2009–2010 representing a small period of time of 1 year were considered to be insignificant to affect the overall changes of the DPL during the study period. In this study, thus, the overall temporal changes in DPL and DG were studied for different time periods from 1975 to 2015 such as 1975–1990, 1990–2000, 2000–2005, 2005–2009, and 2009–2015 as given in (Table 3).

Table 2 Details of characteristics of DPL and DG during different time periods

Time period	Dalung Proglacial Lake Area km^2	Dalung Glacier			
		Area km^2	Length km	Snout altitude m amsl	ELA m amsl
1962	Na	13.73	7.93	4362	4807
1975	Na	12.9	7.71	4406	–
1990	**0.2**	12	7.48	4418	4844
2000	**0.4**	11.65	7.32	4434	4909
2005	**0.41**	11.45	6.81	4451	5012
2009	**0.47**	11.44	6.78	4462	5060
2015	**0.48**	11.09	6.69	4471	5080

Note ELA–Equilibrium Line Altitude

Table 3 Changes in DPL and DG during different time intervals

Time period	Change (Δ)	DPL	DG	
		Area (km^2)	Area (km^2)	Length (km)
1962–1975	Δ	–	0.83	0.22
	Δ %	–	6.44	2.84
1975–1990	Δ	–	0.9	0.23
	Δ %	–	6.94	2.93
1990–2000	Δ	0.2	0.36	0.17
	Δ %	50	2.96	2.22
2000–2005	Δ	0.01	0.19	0.51
	Δ %	2.4	1.67	6.96
2005–2009	Δ	0.06	0.02	0.03
	Δ %	12.7	0.16	0.41
2009–2015	Δ	0.01	0.35	0.1
	Δ %	2.1	3.03	1.41
1962–2015	Δ	–	2.64	1.24
	Δ %	–	19.24	15.7
1975–2015	Δ	0.28	–	–
	Δ %	58.3	–	–

The analysis revealed that from 1975 to 2005, the DG has recessed very rapidly. Consequently, the DPL lake has also expanded rapidly (Figs. 2 and 3). The DPL has expanded rapidly towards backsides against the upward recession of DG. However, after 2005, the expansion of DPL and recession DG has reduced significantly. From

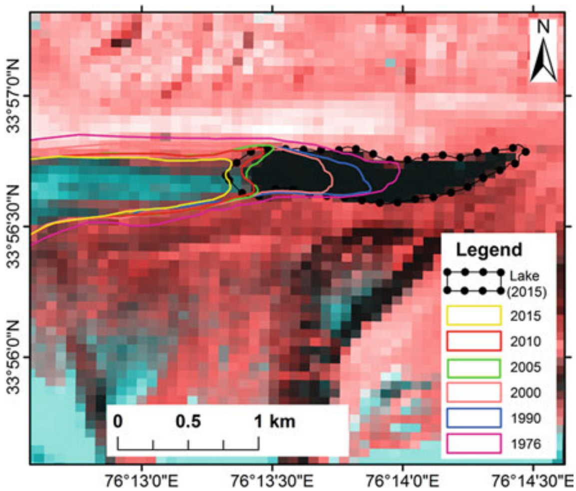

Fig. 2 Recession of DG between 1975–2015 and corresponding expansion of DPL. The background is represented by Landsat TM image of October 2010

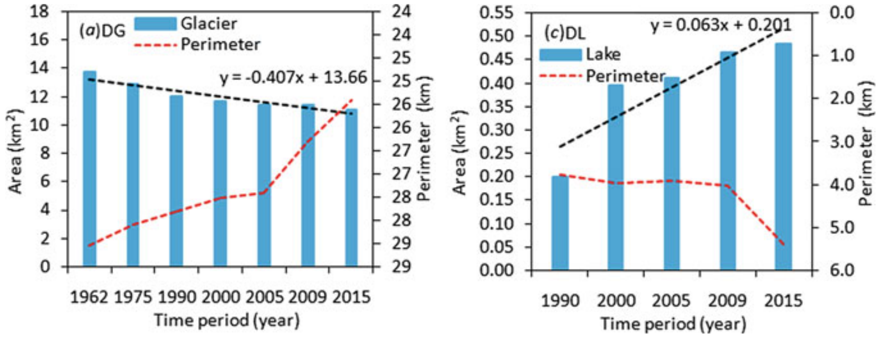

Fig. 3 Changes in (**a**) DG (**b**) DPL between the years from 1962/1990–2015

the analysis, it is inferred that the reduction in backward growth of DPL will lead to increase in the accumulation of melt water vis a vis volume of the lake water over the time. The overall expansion of the DPL during last three decades is shown in (Fig. 4). During the time period from 1962 to 2015, the ELA has been observed to have gone up by about 273 m from 4807 m a.m.s.l. (1962) to 5080 m a.m. s. l. (2015). The shift in ELA indicates a direct influence of climate change on the behavior and dynamics of the glacier in the study area. Similarly, the snout of the glacier has also moved up by about 109 m from 4362 m a.m.s.l. (1962) to 4471 m a.m.s.l. during the last five decades (Table 3).

4.2 Characterizing DPL as Potentially Dangerous

The detailed criterion as given in (Table 4) has been used to investigate and characterize DPL as potentially critical and dangerous lake. These criteria and different indices are developed and described in detail by Mir et al. (2018). In this study, the lake condition, dam condition, conditions of the associated glacier and topographic features around the lake and glacier, area/volume of lake, breaching evidences have been evaluated and investigated using the remote sensing data supplemented with high-resolution Google Earth images (≤5 m). The DPL is having the areas >0.10 km^2. Furthermore, the volume of DPL was determined to be about 11.64 million m^3 respectively. The DPL is located at the snout and connected with the mother glacier, i.e., lake is present in ablation zones of their glacier. The icebergs floating within the lake are clearly visible from the Google Earth images. Additionally, the terminal moraine dam consists of a narrow spillway of about 5 m width is also seen from the Google Earth images. It is important to note that the continuous growth and expansion in the lake area during the last three decades has been clearly related to the continuous glacier recession during the same time period. The crevasses are identified clearly above at a distance of 1 km from the snout within the glacier tongue, which are considered to be the source of ice down-wasting which may slide into a

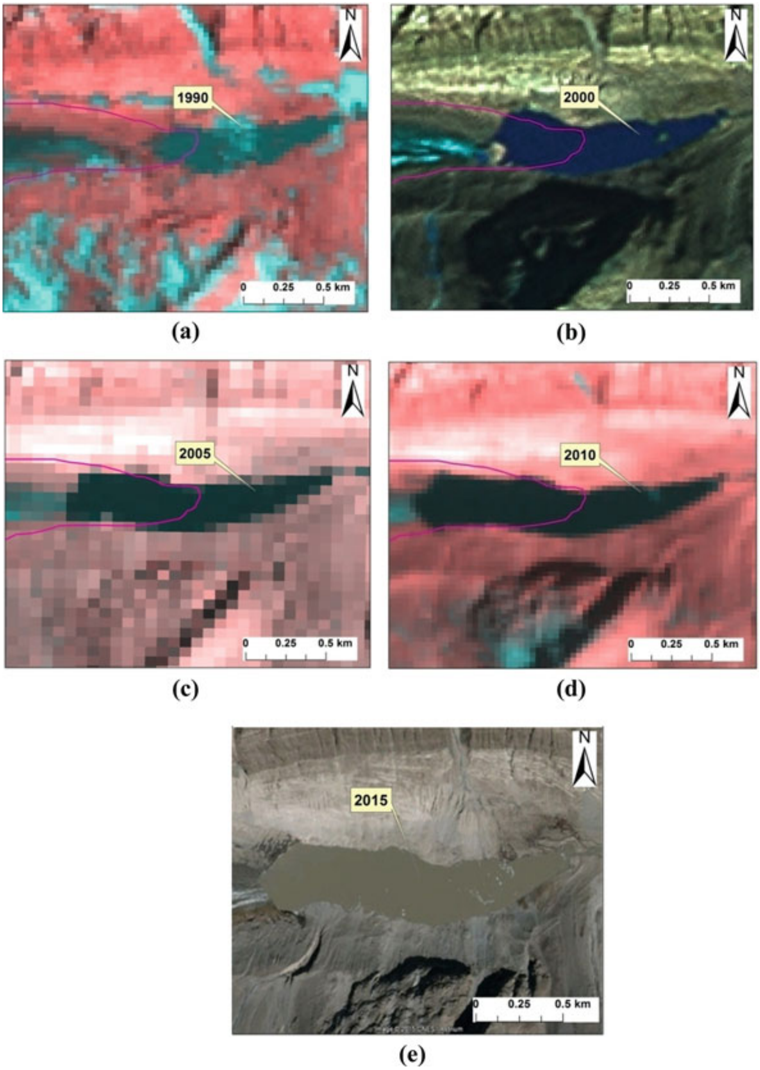

Fig. 4 Satellite images showing progressive growth of DPL (**a**–**e**) between 1990–2015 during different time periods

lake. Although, at present, the mass movements are considered unlikely to enter the lake, but due to the continuous retreat of the glacier, further lake growth is certain to occur in the future. The morphometric characteristics (slope and relative relief) of the glacier and their surroundings are additional important factors that were assessed. The characteristics of the side moraines as well as the freeboard conditions were also manually estimated based on the ASTER-DEM. In this study, the freeboard was found to be low ($\leq$3 m). The moraine dams were found to consist mostly the

Table 4 Details of the adopted integrated criterion for the characterization of the DPL as potentially dangerous

Index	Criteria	Frequencies	Weight	DL
Glacial lake type	End moraine-dammed	10	0.15	Moraine-dammed Lake
Lake area	>0.2 km^2	10	0.15	0.48
Distance between lake and its mother glacier	<500 m	10	0.15	At the snout
Glaciers average slope	>7°	7	0.10	19.5
Downstream slope from lake	>10°	7	0.10	17
Top width of dam	<60 m	7	0.10	46
Glacier area	>2 km^2	6	0.09	11.09
Slope between lake and its mother glacier	>8°	5	0.07	14
Lake area dynamics and changes	>10% of decade	4	0.06	0.08 (20%)
Lake elevation	>5000 m amsl	2	0.03	5014

unconsolidated and granular glacial deposits based on close visual interpretation of high-quality images of Google Earth. These unconsolidated deposits are considered easily erodible (Jain et al. 2012; Agarwal et al. 2013; Jain and Mir 2018). Additionally, the heavy precipitation if any or a glacial outburst flood formation adjacent to ice mass may cause a rapid increase in lake level and volume. The enlarging water level may result in a subsequent enlargement and down-cutting of an existing spillway, or the initiation of a new channel within the moraine dam (Worni et al. 2012). Moreover, the Himalayan Mountain range is tectonically active, so this trigger should also be considered to act as a triggering agent. The seismic activity is generally a common cause of mass movements in the Himalayan region.

4.3 Mechanism of GLOFs

There are a number of causes and mechanisms of GLOF events (Mir et al. 2018). However, a typical trigger event is normally required for a GLOF to initiate and occur. In this study, the formation, the growth rate of the DPL was found almost linear and it is very likely that the lake will continue to grow in future in response to mother glacier recession under warming climatic conditions. Therefore, there are chances of breaching of the lake in future, if the current rate of recession of the glacier and expansion continues. The hydrostatic pressure due to the resulting large volume of glacier meltwater is expected to increase due to rapid glacier thinning. The glacial meltwater is stored behind the naturally occurring moraines which are normally considered to be unstable due to the unconsolidated composition. In addition to continuous increase in lake area (large area >0.10 km^2), small distance to the outlet of the basin and steep slope of the stream from the lake, terminal moraine which dams the lake is also highly susceptibility to fail.

In addition, the danger from mass movements/ice avalanches and climatic conditions are considered to be significant. The most significant is the danger from ice avalanches, debris flows, rock fall, or landslides reaching a lake. Moreover, the morphometric characteristics of the glaciers considered here were found to be the significant factors of triggering. To analyze morphometric parameters factors, the area was divided into 5 slope classes using the ASTER-DEM after the classification of Reynolds (2000). The slopes steeper than >45° were separated and considered to be the probable source areas for mass movements and avalanches (Fig. 5). To analyze, the site of ice avalanches, the profile curvature of the catchment was generated. A convex area at a distance of about 1.5 km of the DPL might rather cause the material to fall or slide into it. Furthermore, the slope of the glacier tongue was observed to be less than <10°. However, this classification was seen under the aspect that the tongues of glaciers are characterized by short steep slopes about 1 km distance from the lakes along the overall gentle terrain.

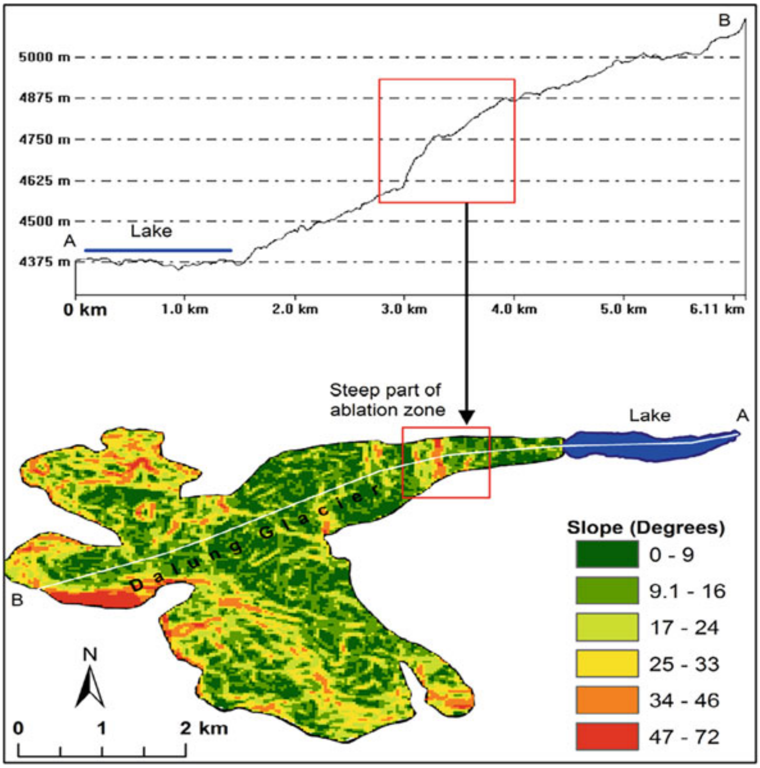

Fig. 5 Length profiles of DG and DPL in the study area

The profiles shed light on the possible sites of mass movements about 1 km away from the lake (Fig. 5). The steeper slope (>45°) is located about 1.5 km away from the lake. There seems to be a significant risk of mass movements into this lake due to steep unvegetated slopes that are considered as a common source of mass movements and can be indicators of high geomorphic activity. In addition, the intensity of GLOF risk is also increased due to the risk of a rock fall or an avalanche due to the steep surrounding relief and tectonically active zone. In addition, due to the continuous warming, the glacier will continue to melt and the lake volume may probably be further increased. The DPL in front of the rather clean mother glacier dammed by moraine has a higher risk of overtopping leading to the formation of a breach and outburst flooding. As observed, the mother glacier has receded faster and the DPL has grown rapidly since the 1990s.

4.4 Modeling GLOFs Using Mike 11

In this study, Mike 11 was applied for one-dimensional hydrodynamic modeling of GLOF from the DPL. To carry out the GLOF simulation, overtopping was considered as the main factor. Based on the empirical equation, the breach width was determined as 60 m. The side slope has been considered as 1H: 1 V and the Manning's roughness coefficient was considered as 0.040 keeping in view the boulder beds and hilly terrain of Himalayan Rivers and the large debris flow mostly associated with GLOFs. The breach timing of the moraine dam was considered as 30 min (Aggarwal et al. 2013; Lohani et al. 2015; Mir et al. 2018). Network Model Setup for MIKE-11 along the stream from late site to downstream site is shown in (Fig. 6).

The dam breach flood i.e., GLOF has been routed through the Suru River over a distance of more than 34 km till the first appearance of the infrastructure/settlement in the valley (Fig. 7). The river profile from lake site down to the catchment outlet covering a total length of 34 km has been represented by a number of cross sections at an interval of 1 km in the model (Fig. 7).

As per the results from Mike 11 model, a GLOF peak of 3361.7 m^3 s^{-1} was found at the lake site which was reduced to 1520.9 m^3 s^{-1} peak at the catchment outlet, i.e., downstream site. The total time of travel of flood peak from the lake site to catchment outlet was found to be about 1 h and 42 min. There is almost a half attenuation of the flood wave magnitude between the lake site and the catchment outlet. The flood hydrographs of GLOFs are shown in (Fig. 8). The total flood peak due to GLOF and its travel distance from GLOF site are given in (Table 5).

5 Concluding Remarks

In this study, multi-temporal satellite and other ancillary data sources have been used to evaluate the temporal dynamics of the Dalung Glacier (DG) and its Dalung

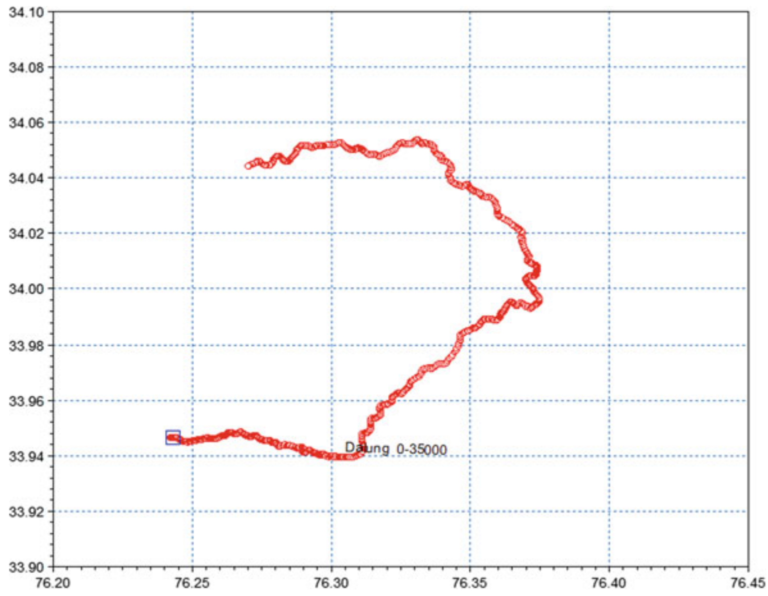

Fig. 6 MIKE 11 network model setup for GLOF study along the stream from DPL to downstream site

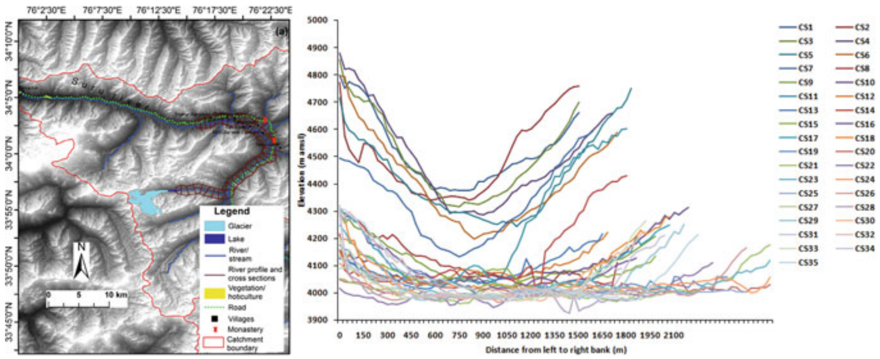

Fig. 7 Location of river cross sections, and land use land cover features downstream the DPL

Proglacial Lake (DPL) located in Indus River Basin, Western Himalaya. The DPL has increased by 0.48 km^2 during the last 4 decades in response to its mother glaciers shrinkage by 19.2% at a rate of 20 m a^{-1} between the years from 1962 to 2015. The rise in ELA as indicated in this study is probably as a consequence of ongoing climate change in the area. Due to the continuous recession of DG, the moraine dammed proglacial lake (DPL) has expanded continuously during the last three decades from 0.20 km^2 (1990) to 0.48 km^2 (2015), indicating a gradual and rapid expansion of 0.28 km^2 (58%) at a rate 0.011 km^{2}a^{-1}. The DPL is also found potentially dangerous based

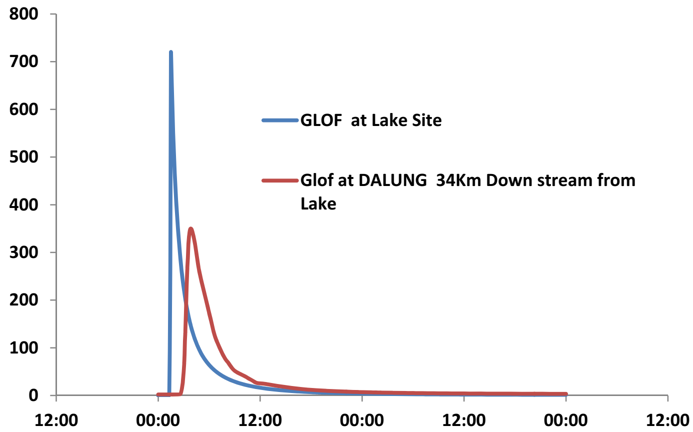

Fig. 8 GLOFs hydrographs at lake site and downstream site of DPL using Mike 11 model

Table 5 Flood peak due to glacial lake outburst for DPL

Name	DPL	
Location	Just downstream of lake site	Catchment outlet
Distance from lake site (km)	0	34
Total GLOF Peak discharge (m^3s^{-1})	3361.7	1520.9

on standard indices. Therefore, MIKE 11 model was used for the one-dimensional hydrodynamic modeling at the late site and downstream site. At the lake site, the peak of the flood hydrograph was estimated to be 3361.7 m^3s^{-1} which after traveling over a distance of 34 km is reduced to 1520.9 m^3s^{-1} at the downstream site. Overall, the results indicated a higher GLOF potential of the DPL and a low damage potential as there is a moderate development of the infrastructure in this area. However, a detailed investigation in the field and a regular monitoring of the lake is recommended for mitigation of any hazard event from the lake in the future.

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Hybrid Tree-Based Wetland Vulnerability Modelling

Swades Pal and Satyajit Paul

Abstract Wetlands of the moribund region of the Ganga–Brahmaputra deltaic part experience extreme loss and degradation, which is the leading cause for our present study. In this study, the vulnerable situation, as a part of degradation, is explored using tree-based ML algorithms in python environment using eight conditioning parameters, namely: water presence frequency (WPF), change in WPF, hydro duration, water depth, agriculture presence frequency, proximity to the river, distance from the road network, and built-up proximity. Four tree-based machine learning algorithms, namely, bagging classification model, reduced error pruning tree (REP Tree), gradient boosting classification model (GBM), and AdaBoosting classification model (ADB), has been used to evaluate the vulnerability of wetlands for both phase II (1998–2007) and phase III (2008–2017). It is found that 23.92–25.01% and 44.67–46.99% area to total wetland area emerged as high to very high vulnerable zone in phase II, whereas 24.08–26.16% and 45.41–49.13% of wetland area identified as high to very high vulnerable zone in phase III. More than 45% of the total wetland area disappeared during phase II to phase III. The models have been validated using the following matrices like sensitivity, Precision F1-score, and MCC for justifying the best-suited model. With an average score of more than 91 for all the matrices, the gradient boosting classification model (GBM), and AdaBoosting classification model (ADB) exhibit more prediction capability and model accuracy than the bagging classification model, and Reduced Error Pruning (REP) Tree model. With the successful prediction, the study recommends tree-based ML algorithms for such or similar works. The study also warns about growing wetland habitat vulnerability and its negative consequences on socio-ecological benefits.

Keywords Wetland vulnerability · Tree-based algorithms · Moribund delta · Machine learning (ML)

S. Pal
Department of Geography, University of Gour Banga, Malda, India

S. Paul (✉)
Department of Geography, Gour Mahavidyalaya, Malda, India
e-mail: spaulofficial.geo@gmail.com

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1 Introduction

The wetland contains a distinctive ecosystem system with significant hydro-ecological functions that have been altered significantly faster than any other known ecosystem (Dong et al. 2020; MEA 2005). Wetland provides 60% of global ecosystem services with only 6% global spatial extension (Finlayson and Davidson 2018). The wetland ecosystem also provides shelter for 40% of global species including some of the most endangered ones (Meng and Dong 2019). Despite immense ecosystem contribution, the wetland is one of the most threatened ecosystems due to rapid change in habitat ecology triggered by agricultural extension, infrastructural developments, population growth in the wetland area (Akpabio and Umoh 2021; Saha and Pal 2019a), hydrological modification (Pal and Debanshi 2021a, b; Talukdar and Pal 2019). Agricultural extension towards wetland areas, directly and indirectly, affects its habitat, and rapid urban growth and infrastructural development deteriorate its habitat completely (Xia et al. 2021). Davidson (2014) reported that 87% of the global wetland has been lost since 1700, with an increasing rate of up to 71% in late 1900. Space Application Centre (2018) reported that 32.5% of Indian wetlands shrink seasonally due to rainfall anomaly and water table fluctuation, which is responsible for ~3% annual wetland loss (Prasher 2018). In the floodplain region, population pressure towards the wetland area with vast agricultural practices leads to accelerate the rate of shrinking (Saha and Pal 2019b; Bassi et al. 2014). The study area moribund deltaic region of the Ganga–Brahmaputra delta is also facing similar situations (Paul and Pal 2020a). This region is enriched with many back swamps, sloughs, oxbow lakes, residual channels, and marshy lands of various sizes. Those wetlands are one of the major sources of various hydrological resources and also act as a corridor for many ecologically sensitive species (Bala and Mukherjee 2010). Studies like Paul and Pal (2020a) reported that 47.31% wetland of this region has been transformed seasonally due to extensive agricultural practices. This seasonal drying out process accelerates the rate of wetland conversion into agricultural lands and built-up land permanently (Paul and Pal 2020b). These factors are very crucial for determining the fate of the wetland, and therefore, these are considered conditioning parameters for wetland habitat modelling.

From the environmental perspective, wetland vulnerability is an ensemble of various natural and artificial factors like rainfall anomaly, lowering down of groundwater table, extensive land use/land cover (LU/LC) change, loss of connectivity with active recharge points, and climatic change (Pal and Talukdar 2019; Finlayson 2006). Current remote sensing (RS) and GIS have such capability to explore the nature of such change using various spatial models like the wetland vulnerability index (WVI) model (Defne et al. 2020), Pressure, State, Impact, Response (PSIR) framework (Mosaffaie et al. 2021), multivariate adaptive regression spline (MARS) (Adnan et al. 2021). Recently, data-driven and knowledge-driven models such as statistical index (SI) (Li et al. 2020), linear discriminant analysis (LDA) (Nie et al. 2020), artificial neural network (ANN) (Paul and Pal 2020b), support vector machines (SVM) (James et al. 2013), Bagging (Chhabra et al. 2021), Boosting (Pal and Paul 2021b), decision tree (DT) (Luo et al. 2021a, b), random forest (RF) (Granger et al. 2021), Random subspace (Talukdar et al. 2021), Reduced Error Pruning (REP) Tree (Pal and Paul 2020), boosted regression trees (BRT) (Shaziayani et al. 2021), Evidential belief function (EBF) (Ghosh 2021), deep belief network (DBN) (Scarpiniti et al. 2021), and naive Bayes (NB) (Costache et al. 2021) are also used to measure different spatial phenomenon like flood and landslide susceptibility mapping (Jacinth Jennifer and Saravanan 2021), groundwater potentiality mapping, climate forecasting (El-Magd and Eldosouky 2021; Lin et al. 2021). Studies show that the machine learning (ML) models have the capability to predict spatial phenomena on large datasets and give more accurate results than traditional statistical techniques (Pal and Paul 2020). Individual machine learning techniques also has some of their strengths and weaknesses, therefore, different ensemble techniques have been introduced to reduce such weaknesses (Rabbani et al. 2021; Pal and Paul 2021a). In a multi-model approach, validation of the model is necessary to check the accuracy level and also ensure the performance of the employed models (Ling et al. 2021). Studies like Mohana et al. (2021), and Qolipour et al. (2021), reported that tree-based ensemble ML algorithms have such capability to perform better than generic algorithms. Recently, various advanced machine learning (ML) algorithms have been incorporated for modelling various environmental phenomena, but the tree-based multi-model approach for wetland vulnerability mapping is rare, especially in this region. Therefore, in this present study, we have attempted to employ multiple tree-based machine learning techniques for modelling wetland vulnerability in the moribund deltaic part of India. Different matrices and an extensive field investigation have been done to validate the performance of the employed models.

Previously, it is mentioned that the moribund of the Ganga–Brahmaputra deltaic region is prone to rapid wetland loss and hydrological transformation due to rapid anthropogenic pressure and infrastructural developments. Previous studies like Mandal and Pal (2017), Paul and Pal (2020a, b), and Everard et al. (2019) focused on only the transformation and dynamic nature of wetlands but no study focused on the degree of risk faced by the habitat or habitat risk areas which have a long-term effect on habitat ecology and ecosystem services of the wetland. Therefore, this study attempts to identify vulnerable areas of wetland with the help of multiple tree-based machine learning algorithms.

2 Study Area

The present study area, moribund deltaic region, is a part of the great Ganges–Brahmaputra delta of Indo-Bangladesh. It extends from 24°30′ N/88° E to 23° N/89°45′ E with a total area of 7685.99 km^2. The extension of our present study is 23°24′35″ N/88°15′50″ E to 23°42′30″ N/88°33′20″ E with an area of 3927 km^2 (Fig. 1). The Ganges–Brahmaputra delta is divided into three geomorphological units and spread across an administrative unit of India and Bangladesh (Bagchi and Mukherjee 1983). The Wetland of this region is enriched by fertile alluvial soil

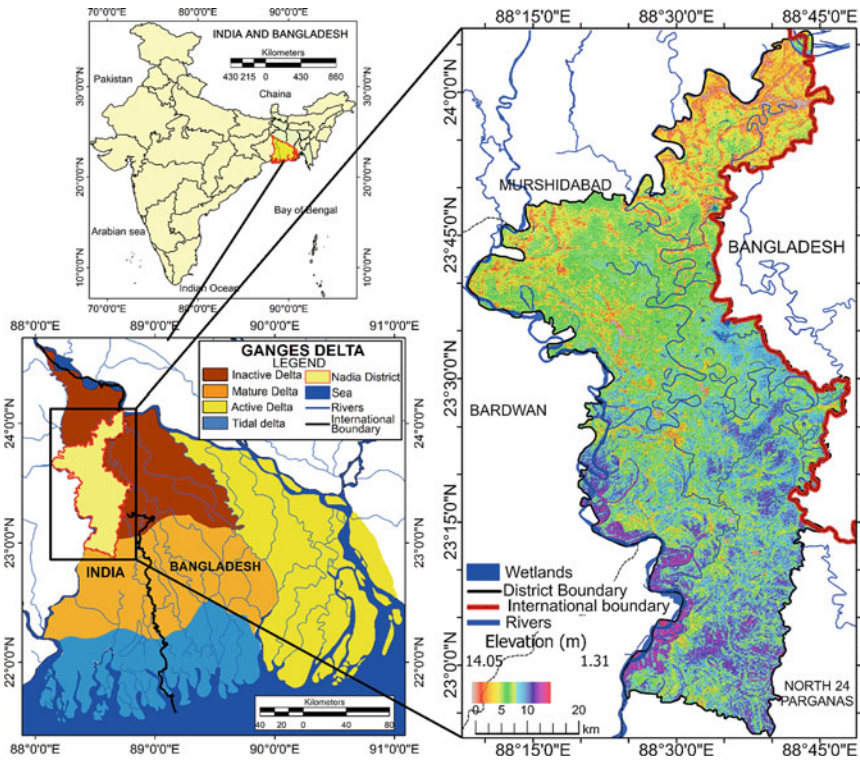

Fig. 1 Geolocation of the study area, moribund delta (Indian part)

and inundated water cane from rivers and depends on the seasonal rainfall regime, and therefore, most of the wetlands are seasonal (Bala and Mukherjee 2010). Since the region receives 80% of total annual rainfall (1450 mm) during the monsoon season, the wetland area gets its maximum areal extent during this season. With an interconnected network of streams like Bhagirathi–Hooghly, Jalangi, Ichamati, and Churni, numerous active riverine morphometric structures create a thick layer of fertile alluvium, silt, and clay layer in this region (Majumdar 1978). Agrarian economy determines the nature of wetland transformation to a large extent.

3 Materials and Methods

3.1 Materials

For this present study, Landsat TM 4–5 imageries ETM and OLI imageries from the United States Geological Survey (USGS) from 1988 to 2017 (Path/row: 138/43,44;

spatial resolution: 30 m) have been used to prepare wetland map, water depth map, seasonal dynamics of wetland, vegetation and agriculture cover map, and built-up area map. Open Street Map (OSM) has been used to prepare a road map. Survey of India (SOI) toposheets have been used to prepare river map. Whereas, the administrative map of Nadia district was used to demarcate the study area because all parts of the Nadia district come under the moribund part of the Ganga–Brahmaputra deltaic region. Extensive field surveys and high-resolution *Google Earth* imageries have been used to validate wetland map, built-up map, agricultural map, and road map. A total of 540 sites has been selected for validating the models.

3.2 Methods

3.2.1 Data Layers Preparation for Wetland Vulnerability Assessment (WVA)

Eight spatial data layers have been considered for this present study, among which five parameters are related to the hydrodynamics of the wetland, namely, water presence frequency (WPF), water depth, change in WPF, hydro duration, and proximity from the river. The remaining three parameters such as distance from the road network, built-up proximity, and agricultural presence frequency (APF) are related to LU/LC dynamics. For this present study, the range of available data (1988–2017) has been divided into three phases in a decadal manner such as phase I (1988–1997), phase II (1998–2007), and phase III (2008–2017). Due to the lack of availability of the change in the WPF layer for phase I, this phase has been excluded.

The normalized differences water index (NDWI) (McFeeter 1996) has been calculated for each Landsat image (1998–2017) to identify the wetlands. According to the studies conducted by Mandal and Pal (2017) and Das and Pal (2016), the NDWI technique of surface water detection gives better sensitivity for the Indo-Gangetic region. The NDWI value is higher in greater water depth areas. The NDWI map is used to prepare water presence frequency (WPF) and also wetland depth mapping for this study. Recent NDWI layers have been validated using 987 reference sites selected from Google earth images and field sites. The computed Kappa coefficient (K) value ranges from 0.86 to 0.95, which indicates an excellent match between image-based wetland map and ground reality. The equation to calculate NDWI is as follows:

$$\text{NDWI} = \frac{b_{\text{green}} - b_{\text{NIR}}}{b_{\text{green}} + b_{\text{NIR}}} \tag{1}$$

where NDWI = Normalized Differences Water Index; the green band is indicated by b_{green}; and the near infra-red band is indicated by b_{NIR}. The NDWI value ranges from −1 to 1, where pixel value towards positive 1 indicates maximum availability of water.

Water presence frequency (WPF) indicates the frequency of appearance of water pixels within a selected temporal frame (Borro et al. 2014). Consistent appearance of water pixels considered high WPF and inconsistent appearance of water pixel considered as low WPF (Paul and Pal 2020a). Therefore, WPF can be an important indicator to determine the habitat health status of the wetland. To prepare the WPF layer, each NDWI layer has been converted to the binary image where the presence of water pixel is considered as 1 and non-water pixel is considered as 0. Thereafter, images of each decade have been summed up to prepare a decadal WPF map (Figs. 2, 3). The total frequency of water presence within a temporal span is considered as 100%. The WPF has been divided into three categories such as low WPF (<33%), moderate WPF (33–67%), and high WPF (>67%).

$$\text{WPF} = \frac{\sum_{i=1}^{n} \text{NDWI}}{N_I} \times 100 \quad (2)$$

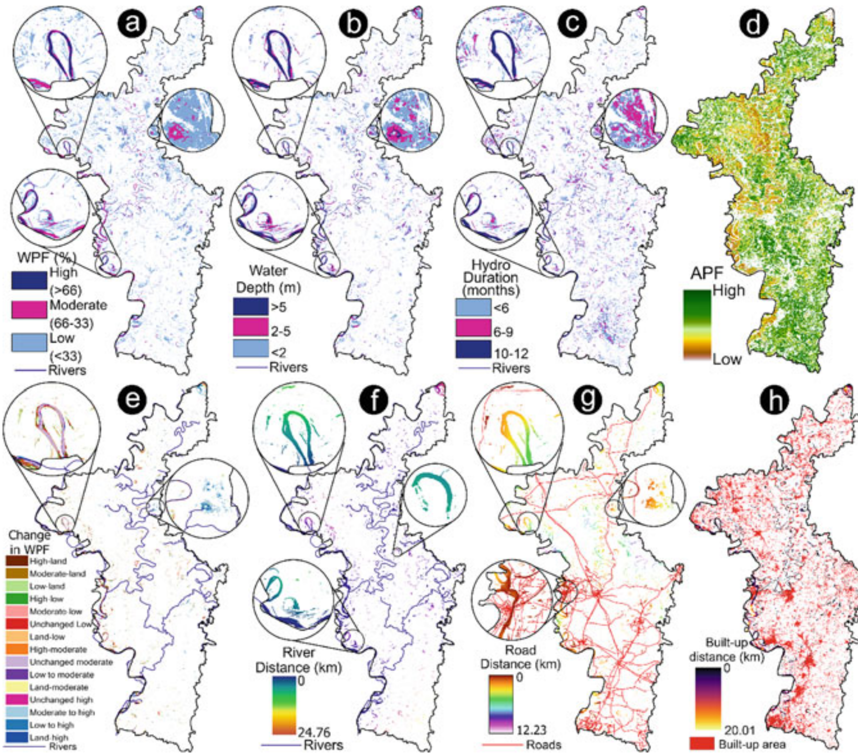

Fig. 2 Incorporated data layers for wetland vulnerability assessment of phase II **a** WPF, **b** water depth, **c** hydro duration, **d** APF, **e** change in WPF, **f** distance from river, **g** distance from road, and **h** distance from the built-up area

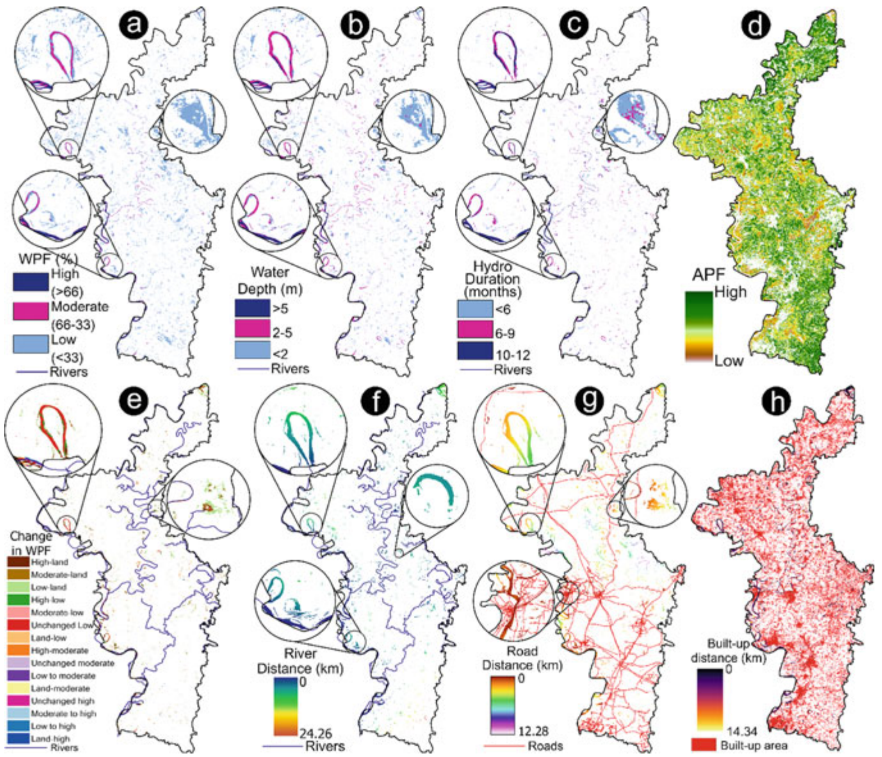

Fig. 3 Incorporated data layers for wetland vulnerability assessment of phase III **a** WPF, **b** water depth, **c** hydro duration, **d** APF, **e** change in WPF, **f** distance from river, **g** distance from road, and **h** distance from the built-up area

In this equation, I_{NDWI} is the frequency of water presence at the Ith pixel, and N is the total number of years.

Imaged-based change detection analysis has been done to detect the decadal change in WPF in the ArcGIS environment. Water depth indicates the potentiality of hydrological richness (Pal and Paul 2021b). NDWI maps have been used to prepare the depth map for this study as the pixel value varies with water depth (Paul and Pal 2021). 30 field-based wetland depth data have been used to calibrate the depth maps. Hydro-duration is another important parameter that indicates the presence and availability of saturated soil periodically (Pal and Sarda 2021). Hydro-duration map phase II and III prepared using 1999 and 2007 for phase and 2010 and 2017 averaging annual hydro-duration maps. This technique has been adopted due to the lack of monthly data for different phases.

In this floodplain deltaic region, wetlands in the riparian region often lost their link with feeding channels in the pre-monsoon season (Pal and Saha 2018). These small tie channels are very important for maintaining water availability and the hydro-ecological health of the wetland (Kundu et al. 2021). Studies made by Pal and Paul

(2021a) and Debanshi and Pal (2020) reported that the wetlands located far away from the perennial channels are generally unable to maintain their stable hydrological status throughout the year. Therefore, distance from rivers can be considered as a potential parameter to check the vulnerability status of the wetland. Phase-wise distance map has been prepared using the Euclidian tool in the ArcGIS environment. The rapid extension of infrastructure causes fragmentation of wetland scape and it is caused for disconnection among the fragmented wetland units and increasing anthropogenic pressure (Grzybowski and Glińska-Lewczuk 2019).

The current study region comprises some populated urban areas like Kalyani, Krishnanagar, Ranaghat, Santipur, and Nabadwip. These cities are well-connected with very dense road networks. Therefore, distance from the road and the built-up area is considered as a potential parameter for detecting the status of vulnerability due to anthropogenic pressure towards the wetland area (Islam et al. 2021). Phase-wise NDBI has been calculated to prepare the built-up distance map and Open Street Map (OSM) road layer is used to prepare the Euclidian road distance map (Figs. 2, 3). In the floodplain region, wetland capture through agricultural encroachment is very much visible (Pal and Saha 2018).

$$\text{NDVI} = \frac{(b_{\text{NIR}} - b_{\text{red}})}{(b_{\text{NIR}} + b_{\text{red}})} \tag{3}$$

$$\text{NDBI} = \frac{(b_{\text{MIR}} - b_{\text{NIR}})}{(b_{\text{MIR}} + b_{\text{NIR}})} \tag{4}$$

Normalized Difference Vegetation Index (NDVI) from 1998 to 2017 (Eq. 3) has been taken to prepare yearly vegetation and cropland maps. Thereafter, each NDVI map is converted into a binary map by providing1 for vegetation and cropland and 0 for the non-vegetated area. These maps are summed up phase-wise to prepare an agricultural presence frequency (APF) map. APF varies from 0 to 100%, where a value near 100% often indicates a consistent cropping area (Figs. 2, 3).

3.2.2 Modelling of Wetland Vulnerability

For this study, four tree-based ML classifiers have been used, namely: Reduced Error Pruning (REP) Tree, Gradient boosting classification model (GBM), AdaBoosting classification model (ADB), and Bagging classification model. A methodological overview of the employed models is discussed below.

Reduced Error Pruning Tree (REP Tree)

The reduced error pruning Tree or REP tree is considered to be a relatively fast decision-making algorithm that uses the pruning method to reduce the complexity of a data model and minimizes the model error (Pham et al. 2019; Sattari et al. 2021).

This pruning process simplifies the model tunning and structurization process and also saves more time during the training (Pham et al. 2019). The pruning process also reduces the overfitting problem and provides better accuracy to the model (Zharmagambetov et al. 2021). There are two types of pruning processes: pre-pruning and post-pruning. The pre-pruning is a relatively faster process with lesser accuracy than the post-pruning (Shahabi et al. 2021). For this study, we have applied the post-pruning technique to assess the wetland vulnerability.

Bagging Classification Model

Bagging or bootstrap algorithm uses bootstrapping technique to reduce the noise in a dataset and improve the performance of the model (Luo et al. 2021a, b; Song et al. 2021). It is one of the primitive ensemble models which generates multiple randomly to form a training set (Wen and Hughes 2020; Jain and Xu 2021; Ankar and Yadav 2021). The bagging model decreases the variance of classification error to improve classification accuracy. For this study, we have used the *SK-learn* package in python to run this model.

Gradient Boosting Classification Model (GBM)

The gradient boosting classification model (GBM) is an ensemble model which uses a decision tree algorithm under the hood (Zhang et al. 2021; Abdi 2020). The GBM algorithm uses boosting tree technique over the generic tree-based algorithm for optimizing the model accuracy and performance (Yang et al. 2021). The GBM algorithm replaces "best-fit" optimization with a "weak" learner model for staking the model and applying aggregation of the existing dataset (Jun 2021). GBM has high predictive power over RF, but for noisy data, sometimes it leads to overfitting (Yang et al. 2021). For this study, *GradientBoostingClassifie*r from the Scikit-learn ensemble package has been used for wetland vulnerability mapping.

AdaBoosting Classification Model (ADB)

Adaptive boosting or AdaBoosting is also a decision tree-based ensemble model designed to improve the performance and efficiency of binary classifiers (Zharmagambetov et al. 2021). Like other ensemble models, AdaBoosting also uses an iterative process to learn the mistakes of multiple weak classifiers and improve the model's performance (Zharmagambetov et al. 2021; Walker 2021). AdaBoost classifier tools from the *SK-learn* ensemble library have been used in this study.

3.2.3 Data Preparation and Training of the Models

To construct a wetland vulnerability model, vulnerability conditioning factor layers water presence frequency (WPF), change in WPF, water depth, hydro duration and proximity from the river, wetland road distance, built-up proximity, and Agricultural presence frequency) have been converted to grid cell format with a spatial resolution of 30 m. Subsequently, the frequency ratio for each lower-class area of WPF (<33%) and depth map has been taken to identify poor wetland habitat areas for both phases. These maps have been used to extract training and validation datasets for the ML algorithms.

3.2.4 Parameter Optimization of the Models

K-fold cross-validation technique along with hyperparameter optimization technique like *GridSearch CV* method has been applied to optimize the model. All ML algorithms are optimized to a certain number of iterations using the grid search technique to generate hyper-parameters (Daviran et al. 2021). The training sets have been split into some equal random k-sets for training and validation of the model as a standard procedure (Wen and Hughes 2020). For better performance and accuracy, 5- and tenfold *K* iterative processes for 240 candidates have been run to generate 1200 and 2400 fits for each model.

3.2.5 Evaluation and Comparison Methods

In this study, the models have been evaluated using six matrices, namely: sensitivity, precision, FI-score, and MCC. The confusion matrix for the training and validation dataset consisted 2 × 2 contingency table from which four types of evaluation results have been categorized as, true positive or TP, false positive or FP, true negative or TN, and false-negative or FN. The TP and TN are correctly classified data, whereas the FP and FN part of datasets are incorrectly classified results. Based on these four classification results, sensitivity, precision, FI-score, and MCC are calculated using the following equations:

$$\text{Sensitivity} = \frac{Tp}{Tp + Fn} \tag{5}$$

$$\text{Precision} = \frac{Tp}{(Tp + Fn)} \tag{6}$$

$$F1 - \text{score} = \frac{\text{precision} \times \text{recall}}{\text{precision} + \text{recall}} \tag{7}$$

$$\text{MCC} = \frac{Tp \times Tn - Fp \times Fn}{\sqrt{(Tp + Fp)(Tp + Fn)(Tn + Fp)(Tn + Fn)}} \tag{8}$$

3.2.6 Field-Based Validation Method to Determine Wetland Vulnerability

An extensive field investigation has been conducted to validate and assess the performance of the models and also for measuring the physical vulnerability status of wetlands. For this study, 30 wetlands have been studied from different parts of this region. The selection criteria of those wetlands include site, situation, wetland type, and distance from the feeding channel. A total of 12 vulnerability controlling factors like the connection with a nearby stream, wetland area change, quantity of natural and artificial inflows, quantity of surface outflows, hydrological period of wetland, depth (average), water level fluctuation (monthly), and wetland eutrophicated area are the physical factors, whereas cultivation of fish, presence or absence of agriculture practice, area encroached for agriculture, are considered as anthropogenic factors those are considered to evaluate the vulnerability status of the wetland. A composite rank score has been calculated to derive a factor-wise score and then the final score has been generated using the averaging technique in SPSS software to generate the final wetland vulnerability index (WVI).

4 Results

4.1 Characteristics of the Parameter Layers

Before assimilating all the eight layers, spatial variation of individual parameters can be quantified to comprehend the nature of each factor used for measuring wetland vulnerability. The overall wetland area has decreased from 150.38 to 80.63 km^2, which means more than 45% of the wetland area was lost between phase II to phase III. In case of water presence frequency (WPF), the area under moderate WPF has lowered from 60.57 to 24.59 km^2 between phase II to phase III during the post-monsoon season. The area under high (>5 m) wetland depth also decreases from 41.81 to 23.70 km^2, which indicates that many wetlands have been dried out during phase II to phase III. In the fragmentation dataset, the large core area decreases from 20.60 to 13.63 km^2 from phase II to phase III. The edge and patch areas also decrease from 55.59 to 5.94 km^2 and 24.22 to 13.63 km^2, which indicates growing wetland fragmentation and increasing pressure on the human landscape. The core area of wetlands is less affected as compared to edge and patch areas. In agricultural presence frequency, the area under the high APF zone is increased from phase II to phase III indicates that the low WPF areas area converted into permanent or semipermanent agricultural land by extending agricultural areas. Similarly, the built-up area towards the wetland is rapidly increased from phase II to phase III, which is also a cause for rapid wetland conversion. It is the fact that all the parameters are not concentrated in the same spatial unit or same spatial variability, therefore, to produce the final vulnerability model, it is necessary to integrate all the spatial layers.

4.2 Wetland Vulnerability Assessment (WVA) Modelling

Based on the tree-based machine learning technique, four vulnerability models for phase II and phase III have been developed. Each output model is classified into five subtypes (starting from very low to very high vulnerability) based on varying vulnerability intensities (Figs. 4, 5). In phase II, 102.88 km^2 (2.64%), 102.55 km^2 (2.63%), 104.55 km^2 (2.68%), and 106.96 km^2 (2.74%) areas are predicted as very high vulnerable category by the Bagging, REP Tree, ADB and GBM models, respectively (Table 1). These four vulnerability models indicate that more than 2.5% of wetland area belongs to a very high vulnerable zone in phase II. In phase III, the area under the very high vulnerable zone has declined to 53,67 km^2 (1.37%), 52.91 km^2 (1.36%), 55.37 km^2 (1.42%), and 56.12 km^2 (1.44%) for all four models in the same order. The area under high vulnerable area is almost twice than the very high vulnerable area. Wetland proximity to a perineal channel(s) tends to be hydrologically more secure than the wetland located away fromthe river. The overall wetland area under different vulnerable zones reduces from 426.28 km^2 (10.92%) to 215.14 km^2 (5.51%). This indicates that almost 50% of the wetland area lost since phase II among which most of the wetlands belong to the high to very highly vulnerable wetland category (Figs. 4, 5).

4.3 Assessing the Accuracy of the WVA Models

Table 2 depicts the model validation result for WVA using sensitivity, precision, F1-score, and MCC. The value for the matrices ranges from 0 to 100, where a value of 100 indicates good accuracy >88% accuracy level found in case of all the applied models. The model's sensitivity score is more than 89 in case of bagging and REP tree classifiers. Whereas, the sensitivity score increases to more than 90 for ADB and BGM models. Precision, recall, and MCC score has similarity to sensitivity scores for all the models (Table 2). The accuracy level for *k10* is lower than the *k5* value. The model's accuracy level tends to be higher in phase III as compared to phase II (Table 2). Among the four ML models, it is observed that the GBM and ADB models perform better in comparison to bagging and REP Tree models for both the phases II and III. Apart from this, the overall performance of all ML models is good for wetland vulnerability assessment and mapping.

4.4 Factor-Based Wetland Vulnerability Index (WVI) Analysis Using Filed Data

Based on the average rank score, the wetland vulnerability index (WVI) has been calculated on 30 selected wetlands in this region. The average score value has

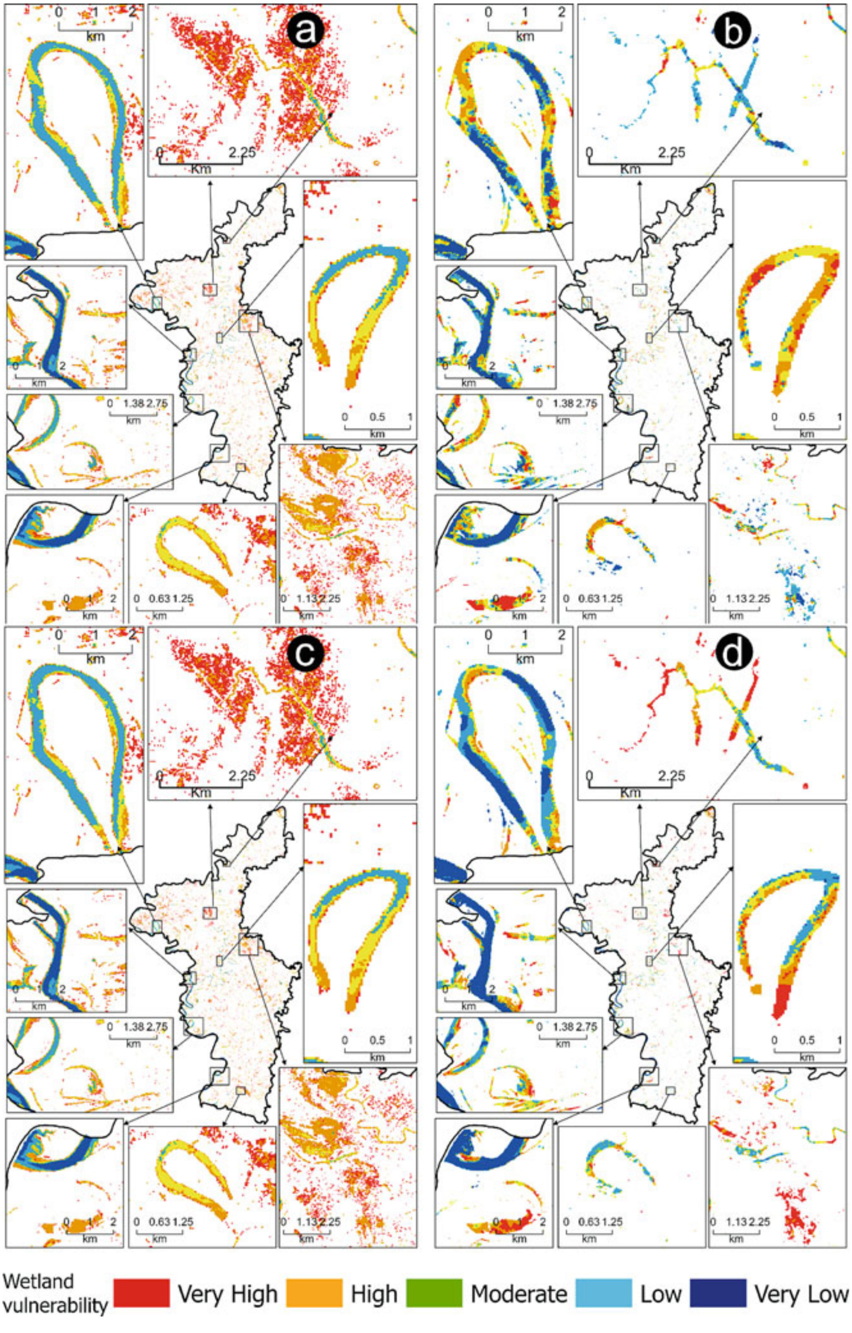

Fig. 4 Wetland vulnerability zones derived from bagging classifier **a** phase II, **b** phase III and REP Tree classifier, **c** phase II, and **d** phase III

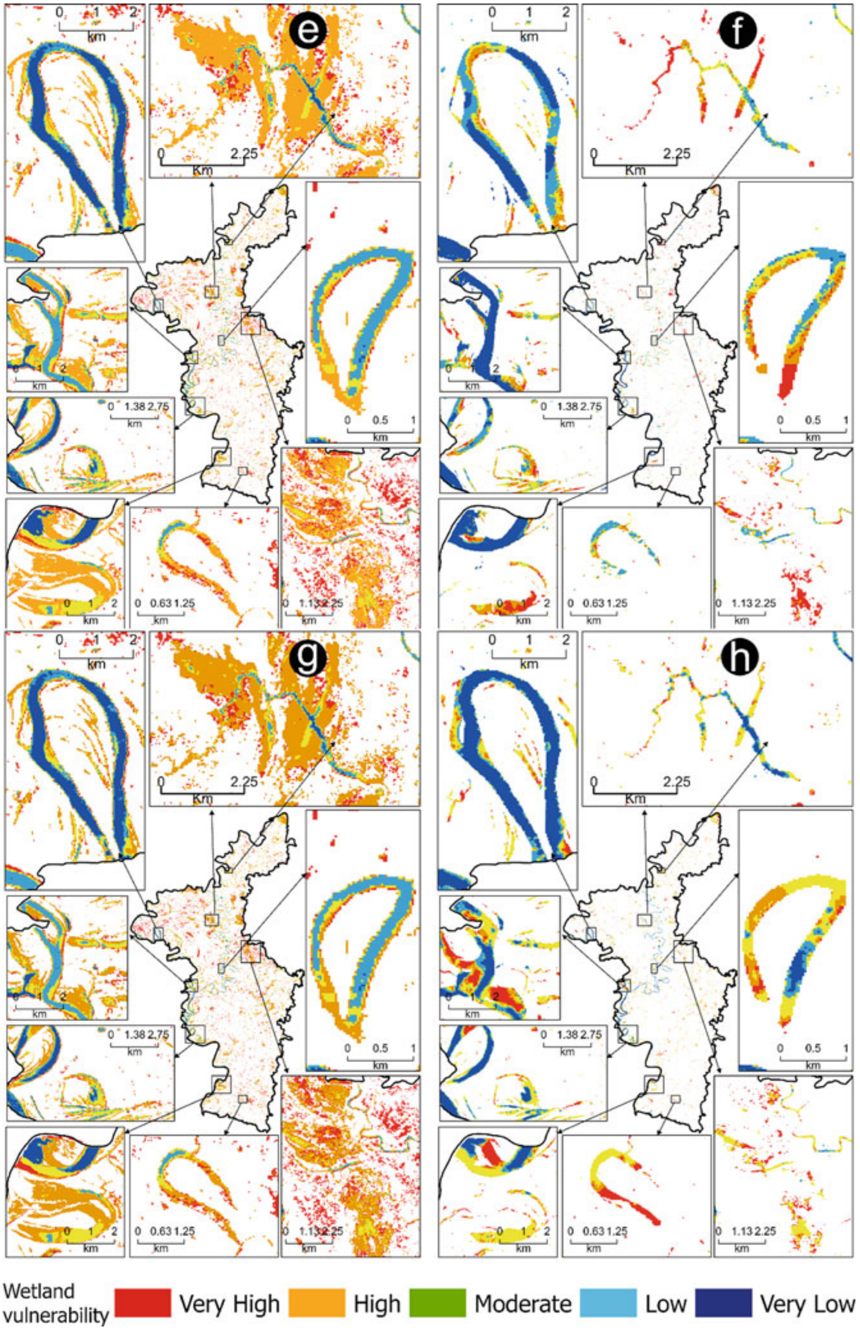

Fig. 5 Wetland vulnerability zones derived from ADB classifier **e** phase II, **f** phase III and GBM classifier, **g** phase II, and **h** phase III

Table 1 Phase-wise wetland vulnerability status based on different ML models

Phases	Vulnerability status	Very high		High		Moderate		Low		Very low	
	ML models	Area (km^2)	Percentage to the total area	Area (km^2)	Percentage to the total area	Area (km^2)	Percentage to the total area	Area (km^2)	Percentage to the total area	Area (km^2)	Percentage to the total area
Phase II	Bagging	102.88	2.64	197.65	5.06	59.51	1.52	41.43	1.06	19.75	0.51
	REP tree	102.55	2.63	183.16	4.69	62.88	1.61	42.98	1.10	18.43	0.47
	ADB	104.55	2.68	198.45	5.08	60.17	1.54	44.04	1.13	19.43	0.50
	GBM	106.96	2.74	210.16	5.38	63.78	1.63	45.68	1.17	20.67	0.53
Phase III	Bagging	53.67	1.37	94.19	2.41	26.88	0.69	20.81	0.53	11.64	0.30
	REP tree	52.91	1.36	91.83	2.35	25.40	0.65	20.33	0.52	11.74	0.30
	ADB	55.37	1.42	102.58	2.63	27.49	0.70	20.87	0.53	11.78	0.30
	GBM	56.12	1.44	114.49	2.93	29.67	0.76	21.03	0.54	11.74	0.30

Table 2 Ground truth accuracies of the models

Phase	Classifiers	K-fold	Sensitivity	Precision	F1-score	MCC	Support
Phase II	Bagging	5	89.33	0.89	0.87	0.87	40,000
		10	89.76	0.86	0.89	0.88	40,000
	REP tree	5	89.23	0.87	0.89	0.88	40,000
		10	90.11	0.84	0.90	0.89	40,000
	ADB	5	91.50	0.89	0.91	0.90	40,000
		10	91.45	0.88	0.88	0.87	40,000
	GBM	5	95.56	0.89	0.87	0.86	40,000
		10	93.21	0.87	0.88	0.89	40,000
Phase III	Bagging	5	89.52	0.89	0.88	0.89	40,000
		10	90.73	0.88	0.89	0.88	40,000
	REP tree	5	90.21	0.87	0.88	0.89	40,000
		10	89.71	0.86	0.89	0.90	40,000
	ADB	5	91.29	0.89	0.87	0.88	40,000
		10	92.46	0.88	0.87	0.87	40,000
	GBM	5	93.65	0.91	0.92	0.90	40,000
		10	92.86	0.89	0.92	0.91	40,000

been reclassified into five sub-categories similar to wetland vulnerability mapping (Table 3). Wetlands like Chaldoba Beel (wetland), Gupiyar Beel, Chuchokhola Beel, Sukna Beel, Mora Ganga, and Charganga 2 are identified as very high vulnerable wetlands with WVI ranges from 11.75 to 10.33. Whereas, wetlands like Bachamari Beel, Padmamala Beel, Chamta Beel, Boro Beel, Gorgore Beel, Nilkuri Beel, and Nabadwip Municipality Lake belongs to high vulnerable wetland category with a WVI score ranging from 9.67 to 9.00. The wetlands like Digri Beel, Chand Beel, Anjana, Chakla Beel, Bhomra Beel, Khalsi Beel, Charganga 1, Tungi Beel, Bahluka Beel, Majhdia Doapara Beel, and Hasnadanga Beel with well-connected recharge points and stable hydro-ecological characteristics belong to low to very low WVI category (Table 2). The correlation coefficient between WVI and WVA ranges from 0.88 to 0.93 which is significant at a 0.01 level of significance. The GBM model with a correlation value of 0.93 came out to be the most significant.

5 Discussion

Wetland risk or vulnerability assessment is a fundamental step towards wetland management and planning. In this present study of the Indian moribund deltaic floodplain region, seasonal hydrological alteration and human intervention towards the wetland area are found as the major triggering factors for exposing wetland habitat towards vulnerability. Intensive agricultural practices during the pre-monsoon season

Table 3 Calculated wetland vulnerability score of some selected wetlands

Wetlands	WVI	State of vulnerability	Wetlands	WVI	State of vulnerability
Chaldoba Beel	11.75	Very high	Arangsartsa Beel	8.42	Moderate
Gupiyar Beel	11.67		Chokar Beel	8.25	
Chuchokhola Beel	11.33		Arpara Beel	7.83	
Sukna Beel	10.83		Mathura Jhil	7.00	
Mora Ganga	10.33		Digri Beel	6.92	Low
Charganga 2	10.33		Chand Beel	6.58	
Bachamari Beel	9.67	High	Anjana	6.42	
Padmamala Beel	9.58		Chakla Beel	6.42	
Chamta Beel	9.42		Bhomra Beel	6.33	
Boro Beel	9.42		Khalsi Beel	6.25	
Gorgore Beel	9.17		Charganga 1	5.50	Very Low
Nilkuri Beel	9.08		Tungi Beel	5.08	
Nabadwip Municipality Lake	9.00		Bahluka Beel	4.42	
Gayshpurkhulia Jhil	8.83	Moderate	Majhdia Doapara Beel	4.17	
Muktaduar Beel	8.50		Hasnadanga Beel	3.92	

intensify the magnitude of wetland loss. The WPF change detection statistics indicate that there is a huge reclamation of agricultural land for crop cultivation which leads to extensive wetland loss. This is also supported by the statistics where more than 50% of the wetland area has been lost during phases II to III. Whereas, the agricultural and vegetation cover increased from 2497.85 to 2654.05 km^2 during phase II to phase III. Scholars like Sampson (2021), Fickas et al. (2016), and Saha and Pal (2019a) reported similar conversions of wetland areas due to agricultural extension in their studies across flood plain wetland. The present study also shows that the process of wetland conversion is deeply related to the rate of wetland fragmentation by which moderate to moderately large wetlands are divided into many small numbers of patches with small core areas. Small wetlands are the most vulnerable to such conversion and loss, whereas the large wetlands with relatively stable core areas somehow maintain their integrity. But the edge area of such large wetlands is significantly shrunken from phase II to phase III (Figs. 4, 5). The large core area decreases from 20.60 to 13.63 km^{2}during phase II to phase III. Extension of the built-up area and connected transportation networks increased from 913.58 to 1094.27 km^2 from phase II to phase III which is a reason behind wetland fragmentation in this region. Change in WPF also indicates that a large number of wetlands converted into ortho fluvial wetland from para fluvial wetland from phase I to II and also phase II to III (Figs. 2, 3). Rainfall is the only source of water for these orthofluvial wetlands, which rarely receive water from the river. Also, connectivity loss from the main feeder channels and lowering of groundwater table due to anthropogenic interferences negatively affects the habitat condition of these wetlands (Pal et al. 2020; Gómez-Baggethun et al. 2019).

Apart from the contemporary conditioning factor, historical hydrological evolution is also a reason behind the present geomorphic setting of the wetlands. Historically (around the sixteenth century), this part of the deltaic region had gone through massive hydrological alteration. In 1975, after the construction of the Farakka barrage, a massive wetland conversion in this region has been occurred (Hirst 1916; Pal 2011). Studies by Paul and Pal (2020a) reported a loss of 63.34% of wetland area from 1987 to 2017.

This present study successfully explored the predictability of tree-based WVA using four tree-based machine learning approaches. The result of four ML models is compared with field-based data to check the applicability of the models. Among the four models, ADB and GBM model performs better and gives better accuracy in comparison to the Bagging and REP Tree model (Table 2). The overall performance of the GBM model is better than the other three models. But overall, all four models perform more than satisfactory as found from the accuracy assessment matrix results (Table 2). The bagging and REP Tree model was reportedly given better results in the studies like Pal and Debanshi (2021a, b), Talukdar et al. (2021), Pal and Paul (2020), and Khatun et al. (2021). The accuracy level of all four models has been increased in phase III and also for fivefold *K* classification. The complex ensemble models have proved their superiority over the comparatively simple bootstrap algorithms. Studies made by Chen et al. (2018a, b, c) and Han et al. (2019) also reported better performance of ensemble models over the generic ML models. It should be mentioned that the spatial extension of WVA zones varies through their geospatial distribution which is similar to each other. Since the wetland habitat is a complex interactive system, and it is controlled by different controlling factors, all the factors do not equally impact control on the spatial extension of vulnerability. Hydrological factors are found more dominant than LU/LC factors. This finding has further clarified that hydrological modification is a dominant reason for wetland conversion and promoting land use transformation causing wetland loss. Pal and Paul (2021b), and Debanshi and Pal (2020), also reported that hydrological insecurity enhances landscape insecurity.

Wetland vulnerability assessment using such advanced tree-based ML algorithms is often rare but there is further scope for research in the future. The present study has focused on only mapping the state of vulnerability and changing the nature of such vulnerability without considering the parameters like river discharge, quality of water, and ecological productivity issues. The inclusion of those factors may uplift the quality of the result. The lack of such extensive spatial data availability restricted us to incorporate those datasets. In future studies, the incorporation of such extensive data regarding complex ecological phenomena can improve the acceptability of such studies a bit more.

6 Conclusion

This present work has assessed wetland vulnerability based on eight decisive parameters using four tree-based ML models. All the models have been validated using five matrices and found to be sensitive. Among all four models, AdaBoosting (ADB) and gradient boosting (GBM) are found as the most accurate to predict vulnerable wetland areas. Very high vulnerable areas have increased over the phases as per all the models. Wetland under greater exposure to the human landscape is more vulnerable to transformation. Hydrological parameters are found to be more important for explaining the vulnerability of wetlands. Hydrological transformation is found as a promoting factor behind land use transformation. From the management perspective, wetland vulnerable models are very important since it provides a database for the future wetland restoration plan. Moreover, since the study has identified hydrological factors are playing a decisive role in wetland habitat transformation, it will be very good information regarding the way of wetland conservation and restoration. In addition to this, the present study tries to build a methodological knowledge addition for wetland vulnerability study which will be helpful for other types of environmental risk assessment studies. In this consonance, the study recommends the use of hybrid tree-based ensemble ML models instead of simple ML models for similar works.

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Spatio-temporal Analysis of Land Use / Land Cover Change Using STAR Method in Kolkata Urban Agglomeration

Sk Mohibul, Lubna Siddiqui, Masood Ahsan Siddiqui, Md. Nawaj Sarif, Neha Parveen, Md. Safikul Islam, Shahanshah Khan, Nazreen Khanam, Mohammad Shariq, and Tania Nasrin

Abstract Land use/land cover (LULC) change has been a key subject of modern research techniques to manage unforeseen development in the urban environment. This work analyzed the spatio-temporal pattern, growth, and development of environmental landscape transformation in Kolkata Urban Agglomeration (KUA) using an unsupervised classification technique and STAR method from 1996 to 2008 and 2008 to 2020. The primary objective of the present study was to generate LULC maps to assess the change rate in the last twenty-four years. The results revealed that negative changes were observed in the wetland and vegetation category which was 7.46% and 7.63%, respectively, while the built-up class increased by 12.92% in the last twenty-four years. The Kappa coefficient and overall accuracy value ranged from 0.821 to 0.864 and from 84.62 to 91.63. It was observed that LULC changes mostly occurred along the transport routes and the existing urban fringe areas. The striking loss of natural wetland and vegetation cover coexists with an increase in built-up cover, hence unplanned urban growth. The current research work may help to understand the dynamics of studied environmental landscape in sustainable urban planning.

Keywords Urban Agglomeration · STAR method · LULCC · Change Detection · Unsupervised Classification

1 Introduction

The term LULC is used interchangeably, land cover in the area of the natural surface that is represented for various purposes like wetland or water bodies, fallow land, impervious surface, scrubs land, grassland, etc., and the land use indicates the area of anthropogenic activities surface with respect to land such as metalled road, cultivable area, commercial, industrial and residential area, etc. The social and economic condition of any area depends on the land use and land cover of the region. But the

Sk Mohibul · L. Siddiqui (✉) · M. A. Siddiqui · Md. N. Sarif · N. Parveen · Md. S. Islam · S. Khan · N. Khanam · M. Shariq · T. Nasrin
Department of Geography, Jamia Millia Islamia, New Delhi, India
e-mail: lsiddiqui@jmi.ac.in

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unusual changes on the surface of the earth are found in almost every part because of the different natural and anthropogenic activities. The environmental and climatic condition changes on a global level are highly connected with the man-made disruptions through the transformation of land use and land cover change (Aguilar et al. 2003; Xiao et al. 2006) The rapid economic development increased pressure on land use/land cover which have changed major portion of wetlands, vegetation, and damaged the fragile environment, especially in prolonged dry seasons, it also influences the groundwater levels, decreases habitat heterogeneity (Brock et al. 1999; Xiuwan 2002; Sondi et al. 2008; Zhao et al. 2010; Guan et al. 2020).

Land use / land cover are very essential to manage the wetland, vegetation, and other significant environmental resources (Kiptala et al. 2013) as LULC changes have occurred in both the impact of different human and natural activities. As a result, fast and reliable data gathering is essential for protecting and planning our environment. The environment and ecology have been changing continuously due to the negative effect of unauthorized and illegal land acquisition and haphazard urban growth. Urbanization has been a key factor influencing land use and land cover change. According to the majority of researchers, more than half of the world's population now lives in cities and urban settlement areas (Obiefuna et al. 2013; Eludoyin et al. 2014). Around 54 percent population of the world resides in urban areas as of 2014 and is estimated to arrive at 60 percent in 2020 and 66 percent by 2050 (United Nations 2015; Jain et al. 2016). According to UN Habitat (2010), urbanization rates are anticipated to be higher in developing and least-developed nations, whereas Zhang and Yifang (2008) estimated that 95% of the net growth in the global population will occur in developing cities such as India and China. In developing countries, rapid urban expansion is frequently linked to and driven by socio-economic problems, and on the other hand, the progress of urbanization has a significant influence on society's economy which shows the reciprocal connection between urbanization and the economy of society (Huang et al. 2005; He et al. 2006). In South Asia, the important center for economic development is Dhaka in Bangladesh, Colombo in Sri Lanka, Mumbai, Delhi, and Kolkata in India, which changes the LULC along with the precious wetland areas like Gulshan lake, Ashulia wetlands, Attidiya marsh, and Muthurajawela and the east Kolkata wetland and vegetation areas. India will be the primary center for urban agglomeration by 2021 due to the rapid increase in the urban population (Taubenböck et al. 2009). The Indian cities have their distinct features. The Kolkata urban agglomeration is very rich both historically and economically in India. Kolkata comes in tenth place among the world's most populous cities (UN 2011). With the increase in population and urbanization (Kumar et al. 2019; Sharma et al. 2007) the encroachment impacts more on wetlands and vegetation leading to land use and land cover change (Ibrahim and P.O, 2013; Okoli et al. 2016). With its natural richness and diversity, the East Kolkata wetland, Hooghly river, ox-bow lake, ponds, and other wetlands are all part of the Kolkata Municipal Development Authority, which plays an important role in the economy of West Bengal (Haque and Basak 2017). As the research region includes several wetlands (East Kolkata Wetland, Alipur Lake, Santragachi Jhil, Nalban, and Rabindra Sarovar) and the population growth is rapid, therefore the landscape authorities must examine and monitor on a regular basis (Mondal, 2009; Sahana et al. 2018).

With rising populations and developing technology, people have had an active part in modifying the environment during the past millennium (Mangan 2014). Many change detection techniques have been created and tested during the last twenty years using remote sensing techniques (Rogan et al. 2002; Healey et al. 2005). Change detection is the technique of detecting variations in the status of an object or phenomenon by examining it at various periods (Singh 1989). In change detection, various aspects (wetlands, built-up areas, agricultural land features) collect the information which provides better knowledge about the relationship between human and natural phenomena, which may allow for improved the resource management in the study area. The following information should be provided by a change detection technique: (1) rate of change; (2) spatial distribution of change classes; (3) land cover change trajectories; (4) accuracy assessment of change detection outcomes; and (5) area change rate (El et al. 2016).

The past works ensure that the different organizations established by the government like East Kolkata Wetland Management Authority (EKWMA), the Land Use Development and Control Plan (LUDCP), Urban Development and Municipal Affairs Department, the West Bengal Pollution Control Board (WBPCB), Calcutta Metropolitan Water and Sanitation Authority (CMW and SA), the West Bengal Housing and Infrastructure Development Corporation (WBHIDCO) all have separate responsibility to monitor the environment (B. Mondal et al. 2017; Ghosh et al. 2018). The organizations focus on town planning, wetland management, waste management, and problems of urbanization. Despite all the KMDA rules and regulations by the different organizations for the planned development of land, it was found that the presence of resources is under threat due to anthropogenic activities. Remote sensing and geographic information system (GIS) techniques can give the idea about different susceptibility mapping, machine learning models, industrialization, urban sprawl matrix, environmental pollution, future prediction, and so on (Sarif et al. 2021; Parveen et al. 2021). The present study is focused on conducting historical morphological LULC evolution, growth rate, and pattern of each class with suitable statistical techniques and the GIS and remote sensing acquisition data. Previously many research works had been done by various researchers regarding land use and land cover change. Though, with the help of past studies, it can be realized that the study area is suffering from a lack of updated data to determine the change in land use and land cover. This paper clarifies the many variables influencing the LULC transformation, the direction in which it is occurring, and the remedial initiatives undertaken to address the problem in the studied region.

The researcher's major goal was to explore and evaluate the study area's spatio-temporal land use and land cover change rate, dynamic pattern, and growth rate. It also determines the urban spreading out and land use/land cover conversion rates on temporal and spatial scales. The main objectives were to create relevant land use and land cover classification map; to determine the trends of dynamic pattern, change rate, location of land use and land cover for the past 24 years in the Kolkata Urban Agglomeration, and to the detailed understanding of the spatio-temporal change conversion throughout all decades using change matrix. As a result, the two research questions were developed initially based on the stated objectives: what was the nature and pattern of land use and land cover change between 1996 and 2008, and between 2008 and 2020? Secondly, is there any relationship between the landscape changes with each other, i.e., wetland to built-up, vegetation to agriculture? Results can also be used to quantify the nature and extent of the region.

2 Study Area

The Kolkata Urban Agglomeration (KUA) is situated at an elevation of 9 m from mean sea level on the eastern bank of the Hooghly River. KUA is India's third-largest urban agglomeration with an area of 1033 km^2 (Census of India 2011). KUA consists of Municipal Corporation, Municipality, a recently added area in KUA, a newly formed municipality in KUA, and a newly added area of KMC. The entire KUA region along with the non-municipal area is administered by Kolkata Municipal Development Authority (KMDA) (Fig. 1). KMDA covers an area of 1886.67 km^2 which extends from 22°17′ N to 23°03′ N and 88°06′ to 88°52′ E. KMDA has 39 municipalities, 77 census towns, 16 outgrowths, and 446 villages and is situated 80 km away from the International Border of Bangladesh. The number of wards in the city of Kolkata is 144 and the area is 206.08 km^2. The other Municipal corporations of the agglomeration are Howrah, Bidhannagar, and Chandan Nagar (http://www.wburbanservices.gov.in). With a population of 14.2 million in 2011, Kolkata is the largest urban agglomeration in eastern India, with projections of 20 million in 2021 and 21.1 million by 2025 (KMDA 2011). The climatic condition of the region is tropical wet and dry, with average temperature records at 18–35 °C and 165 cm monthly rainfall. The Kolkata Urban Agglomeration plays a vital role in economic development, as well as in local environmental conditions, but the area has faced lots of problems like excessive migration, slum area development, poverty, crime, and unplanned growth.

3 Research Methodology

The present work is based on primary and secondary data. The satellite images for land use and land cover classification were obtained from the United States Geological Survey, Earth Explorer (Table 1). Landsat 5, Landsat 7, and Landsat 8 satellite images were acquired in three different years 1996, 2008, and 2020, respectively. The shapefile of the study area was digitized from the topographical map of the Survey of India.

The STAR method was employed in the present research work as this technique accounts for the land use and land cover relationship and past ideas, its problem, growth rate, distribution of land, generation of the transitional matrix, etc. (Fig. 2).

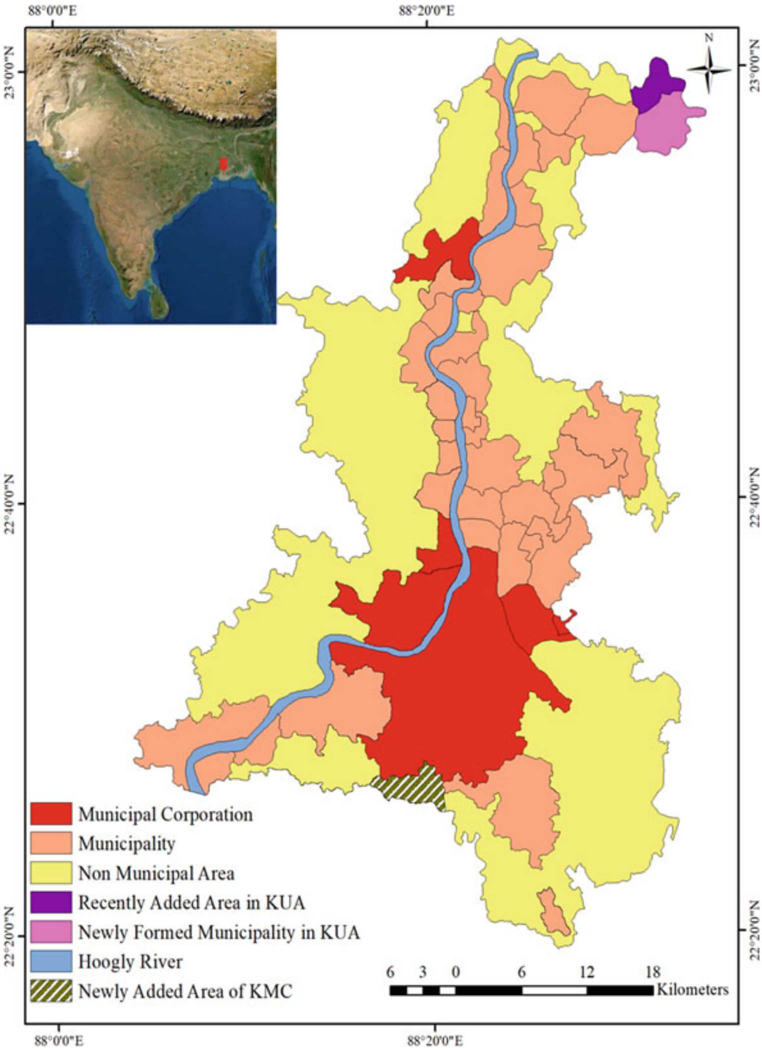

Fig. 1 Location of the study area

Table 1 Description of satellite images

Satellite image	Month and year of acquisition	Resolution	Path/Row	Source
LANDSAT 5	February, 1996	30 m	138/44 138/45	USGS-Earth Explorer
LANDSAT 7	February, 2008	30 m	138/44 138/45	USGS-Earth Explorer
LANDSAT 8	February, 2020	30 m	138/44 138/45	USGS-Earth Explorer

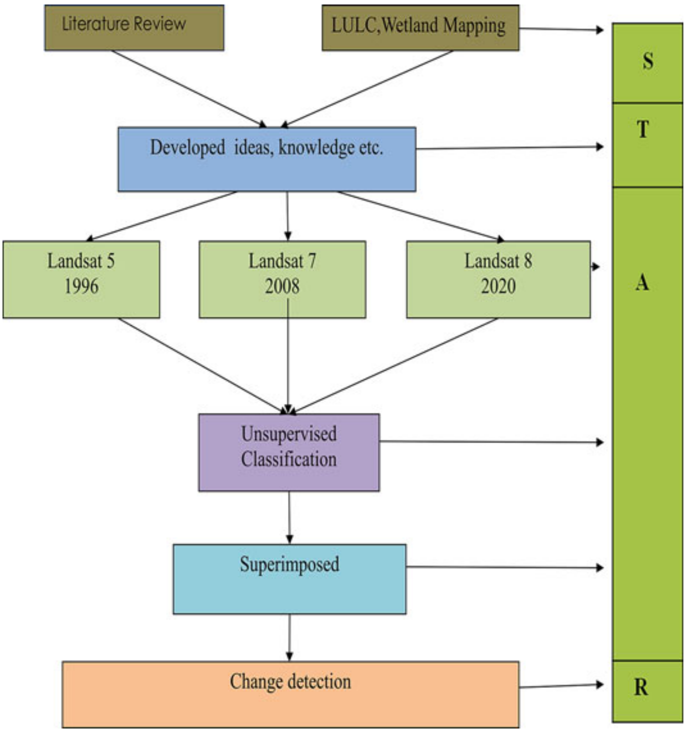

Fig. 2 STAR methodology

'S' represents the situation to understand the conditions of the Kolkata Urban Agglomeration area with the help of a literature review. 'T' refers to a task where gained knowledge, ideas about the study was determined. 'A' means that action where an unsupervised classification technique was run on Landsat images. 'R' represents the results where the analysis of land use and land cover maps, change detection, and accuracy assessment were carried out.

ERDAS Imagine 14.0 software was used to run unsupervised classification to identify land use/cover for the years 1996, 2008, and 2020. The software also helped in the processing of layer stack, mosaic, and a subset of the study area. Landsat images that were used in the study have 30 m spatial resolution. Unsupervised classification is very helpful when there is no pre-existing field data or detailed descriptions of aerial photographs are not available. The user is allowed to assign a meaningful title to each class and each of which mimics a distinct geographical category (Jensen 1995; Das 2009). For unsupervised classification, 350 classes were selected to generate LULC maps for the years 1996, 2008, and 2020. On-screen visual interpretation keys such as tone, form, texture, size, pattern, and association were employed to identify various classes. Five major classes of land use and land cover maps were identified in the present study (Table 2).

Table 2 Land use and land cover classification

LULC classes	Details
Wetland	It involves ponds, rivers, lakes, ox-bow lakes, waterlogged, swamps, marsh, etc.
Vegetation	Tree cover land and grassland
Built-up	Settlement areas, industrial areas, and transportation
Agriculture	Fallow land and cultivated land
Others	Bars in the river, playground, airport, identifiable transportation, wasteland, etc.

To comprehend and estimate the changes appropriately, accuracy assessment is a vital and most significant technique. The accuracy assessment method is the statistical technique that is used to check the correctness of the output of the classified data. For accuracy calculation, 100 simple random sample points were tested and verified with the help of Google earth pro and ground truth. Producer's accuracy was also calculated as it indicates the probability of a pixel being correctly classified and the total number of pixels classified in the same categories (total column) with the help of the following Eq. (1) (Akbari et al. 2006)

$$PA = C_i / C_t \times 100 \tag{1}$$

where

PA = Producer's accuracy,

C_i = correct sample location in the column,

C_t = total number of sample locations in the column.

The User's Accuracy was examined by employing the formula (2). User accuracy indicates the total number of correct pixels in a category divided by the total number of pixels that were classified in the category (total row) (Andualem et al. 2018).

$$UA = R_c / R_t \times 100 \tag{2}$$

where

UA = User's accuracy,

R_c = correct sample location in a row,

R_t = total number of sample locations in a row.

Overall Accuracy was calculated by dividing all correctly classified pixels by the total number of pixels in the error matrix (3) (Andualem and Gebremariam 2015).

$$OA = A_c / A_t \times 100 \tag{3}$$

where

OA = Overall accuracy,

Ac = All correct classified samples from all classes,

At = total number of samples from all classes.

Kappa coefficient was computed by the following formula (4) (Foody 2002; Lillesand et al. 2011):

$$\hat{k} = N\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(xi + .x + i)/N^2 - \sum_{i=1}^{r}(xi + x + i) \tag{4}$$

where

N = sum of all observation in the matrix,

r = number of rows in the error matrix,

xii = number of observations in row i and column i (along the diagonal),

xi_+ = total of observations in row i (total to right of the matrix),

x_{+i} = total of observations in column i (total at bottom matrix).

3.1 Change Detection

After the launch of the Landsat orbital system, change detection techniques were developed and used in the 1980s. Many change detection methods were introduced in the last few decades, including principal component analysis, image subtraction, changing vector analysis, post-classification change matrix, and spectral features variance method, etc. (Lu et al. 2004). But multi-band remote sensing imagery is widely employed as it gives appropriate information about LULC. The measurement and identification of various classes, as well as trends of past, present, and future landscapes could be carried out using remote sensing data of different periods. The quantification of land use/land cover in each class was evaluated to understand the dynamic pattern as it will assist in better administration and planning of the specific region (5–9) (Liu et al. 2000; Yin et al. 2011).

$$AWGR = WG_{p+1} - WG_p/cTA_{p+1} \times 100 \tag{5}$$

where

$AWGR$ = the annual wetland growth rate;

WG_{p+1} and WG_p = wetland growth at time $_{p+1}$and $_p$,

cTA_{p+1} = total area at time $_{p+1}$ and c is the time interval (years).

$$AVGR = VG_{p+1} - VG_p/cTA_{p+1} \times 100 \tag{6}$$

where

AVGR = annual vegetation growth rate;

VG_{p+1} and VG_p = vegetation growth at time $_{p+1}$ and $_{\mathrm{p}}$,

cTA_{p+1} = total area at time $_{p+1}$ and c is the time interval (years).

$$ABGR = BG_{p+1} - BG_p/cTA_{p+1} \times 100 \tag{7}$$

where

ABGR = annual built-up growth rate;

BG_{p+1} and BG_p = built-up growth at time $_{p+1}$and $_p$,

cTA_{p+1} = total area at time $_{p+1}$ and c is the time interval (years).

$$AAGR = AG_{p+1} - AG_p/cTA_{p+1} \times 100 \tag{8}$$

where

AAGR = annual agriculture growth rate;

AG_{p+1} *and* AG_p = agriculture growth at time $_{p+1}$and $_p$,

cTA_{p+1} = total area at time $_{p+1}$ and c is the time interval (years).

$$AOGR = OG_{p+1} - OG_p/cTA_{p+1} \times 100 \tag{9}$$

where

AOGR = annual others area growth rate;

OG_{p+1} *and* OG_p = others area growth at time $_{p+1}$and $_p$,

cTA_{p+1} = total area at time $_{p+1}$ and c is the time interval (years).

4 Results

The land use/land cover change was generated for the years 1996, 2008, and 2020 (Figs. 3 and 4). The LULC map for the year 1996 showed that built-up was covering 36.52% of total KMDA, followed by agriculture land at 27.52%, vegetation at

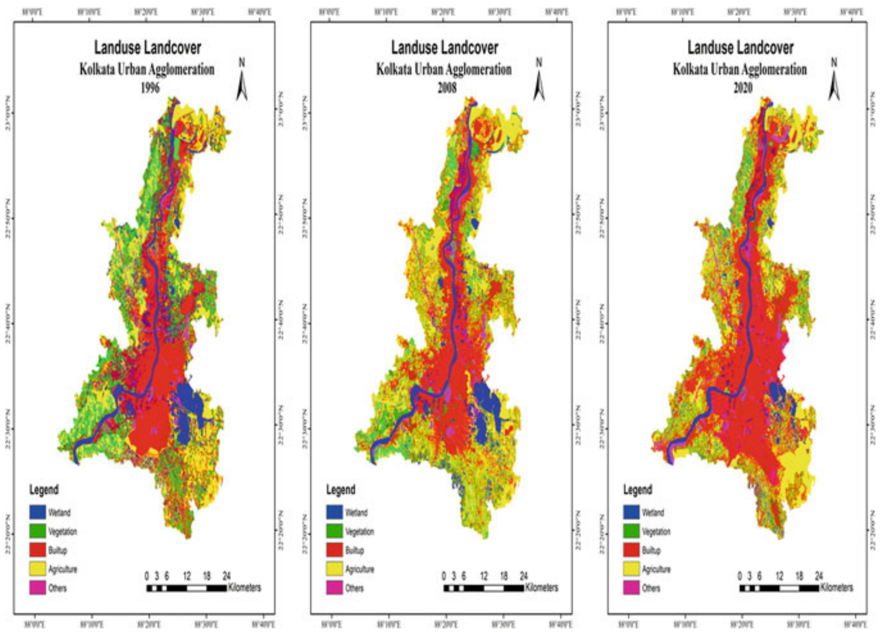

Fig. 3 LULC of Kolkata urban agglomeration

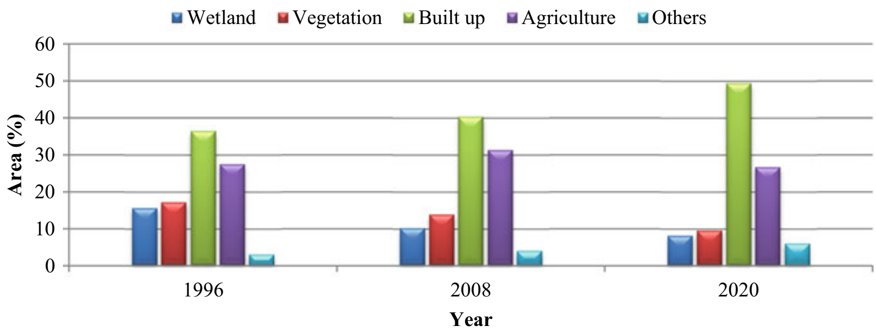

Fig. 4 Areal distribution of LULC

17.20%, wetland at 15.64%, and others at 3.12%. In the year 2008, built-up, agriculture, and other class increased by 3.85, 3.84, and 1.01% area, whereas wetland and vegetation classes decreased by 5.39 and 3.3% area. The LULC map of 2020 manifested that built-up grew continuously; about half of the area covered by built-up at 49.44%, wetland and vegetation reduced to 2.07 and 4.33% in between 12 years periods (2008–2020). Between 1996 and 2020, the wetland area declined by 13,584 ha at a rate of 566 ha per year, the vegetation area started to shrink by 13,892 ha at a rate of 579 ha per year, the built-up area increased by 23,529 ha at a rate of 980 ha

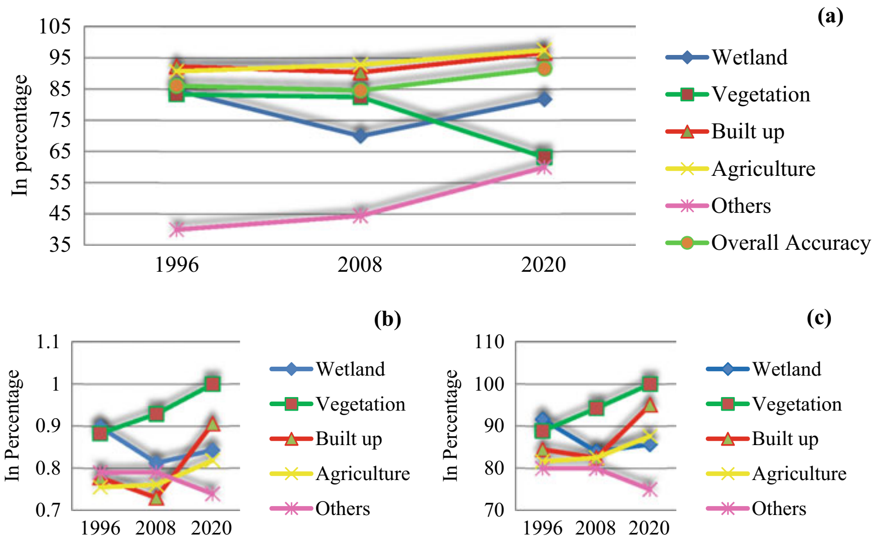

Fig. 5 Producer's and overall accuracy (**a**), Kappa coefficient (**b**), and user's accuracy (**c**)

per year, agriculture slightly decreased by 1460 ha at a rate of 61 ha per year, and other land use/land cover class obtained by 5405 ha at a rate of 225 ha/year.

The classification cannot be completed without showing its validity, the results of this research study included the Confusion Matrix and Cohen's Kappa, which had already been used by several researchers for a better result (Hollister et al. 2004). Using these reference data and the classified maps, confusion matrices were prepared for the three periods (Fig. 5). The overall accuracy of LULC maps was 86.11%, 84.62%, and 91.63% for the period 1996, 2008, and 2020, respectively. The user's accuracy of the individual class ranges between 80 to 92% in 1996, 80% to 95% in 2008, and 75% to 100% in 2020. The producer's accuracy varies between 40 to 93% in 1996, 44% to 93% in 2008, and 60% to 98% in 2020. The Kappa values in the years 1996, 2008, and 2020 were calculated as 0.82114, 0.79, and 0.8647.

4.1 Change Matrix Analysis

The study of LULC transitions helps in determine how a certain land use and land cover has moved from one type of land to another type. The change matrix from 1996 to 2008 was calculated and mapped (Table 3 and Fig. 6). The results showed that 13,393.1 ha of wetland areas were unchanged, but 15,091.3 ha of areas were converted into vegetation, built-up agriculture, and other LULC classes. So the maximum encroachment of the wetland class by built-up areas was 6165.36 ha. But for vegetation and built-up areas, about 10,907.5 ha and 46,101.5 ha areas were

Table 3 Change matrix, 1996–2008

	2008						
	Class name	Wetland	Vegetation	Built-up	Agriculture	Others	Total
1996	Wetland	**13,393.1**	2727.54	6165.36	5232.69	965.7	28,484.4
	Vegetation	568.17	**10,907.5**	9131.49	10,127.3	590.22	31,324.7
	Built-up	2138.49	5663.16	**46,101.5**	10,313.5	2307.96	66,524.6
	Agriculture	2365.11	5707.17	11,289.6	**29,958.1**	804.96	50,124.9
	Others	219.24	301.95	985.14	1295.46	**2874.24**	5676.03
	Total	18,684.11	25,307.32	73,673.09	56,927.05	7543.08	182,135

stable. The maximum transformation of the area in vegetation and built-up into agriculture was 10,127.3 and 10,313.5 ha, respectively. The maximum area was stable in built-up followed by agriculture (29,958.1 ha). The highest conversion was taken place in agriculture to built-up (11,289.6 ha) and others to agriculture (1295.46 ha) in the same period.

The pixel by pixel approach was used to create the change detection matrix for the years 2008 to 2020 (Table 4 and Fig. 7). The results showed that wetlands have been shrinking over the year and changed into residential, cultivation, or other classes. As quantified, the unchanged areas were 9292.56 ha, and the maximum area conversion found in the built-up area was 4579.56 ha. Likewise, from 1996 to 2008 and 2008 to2020, it has been found that more land was transformed into built-up (8545.59 ha) and agriculture (8106.57 ha) areas from vegetation areas. Furthermore, the transition trend of the built-up area revealed the fact that 57,966.8 ha become unchanged. The major portion of the agricultural class was transformed into vegetation and built-up. Moreover, built-up occurred greatly in fringe areas because the migrants prefer to reside in periphery areas as living costs are low as compared to main cities and along the roadways (Reis 2008).

The overall land use and land cover transition from 1996 to 2020 was quantified (Table 5 and Fig. 8). The areas of built-up (10,378.1 ha), agriculture (5626.71 ha) gained the majority of the land from the wetland region, which is higher than the earlier two transition periods (Tables 3 and 4). The transition of vegetation indicated that all categories except agriculture gained the areas predominantly as compared to the previous two transition matrices. The maximum conversion was observed in built-up areas because the urban areas encroached very rapidly than the others. The built-up class encroached the 14,769.8 ha of agriculture area within 24 years of the interval which was the highest of all categories. Finally, the transition between classes showed that 2168.28 ha were stable and 3507.75 ha were converted into a wetland, vegetation, built-up, and agriculture areas.

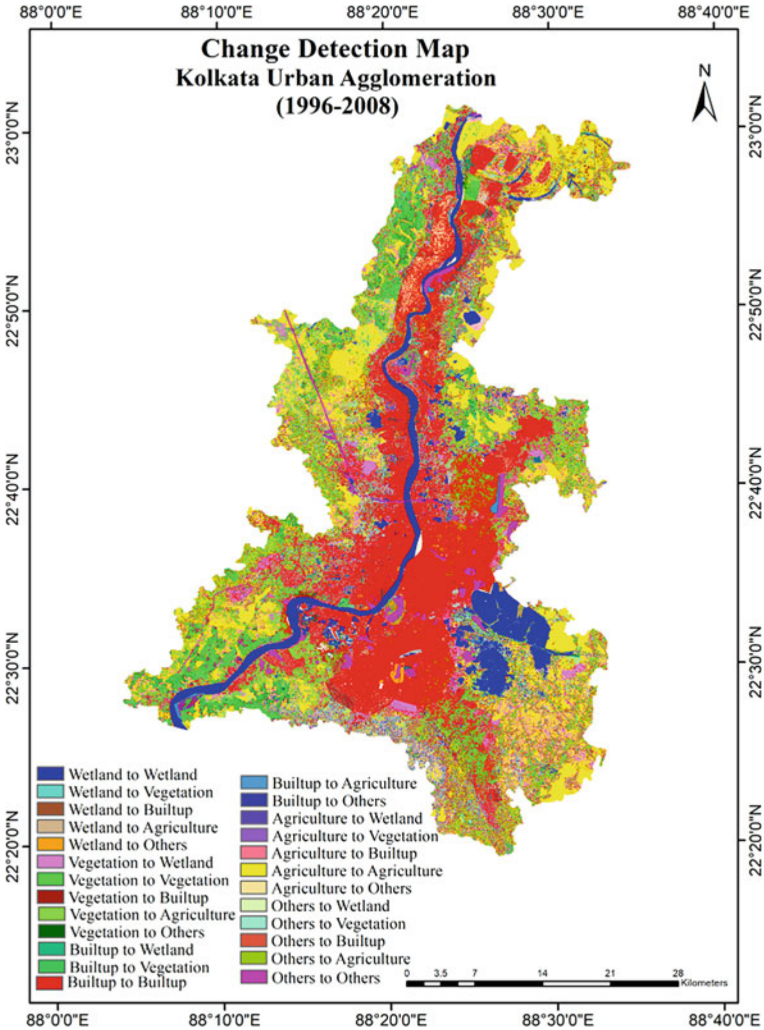

Fig. 6 Change detection, 1996–2008

4.2 LULC Expansion Rate and Change Detection

The trend of land use and land cover growth in each spatial pattern within the study area was also examined. The positive growth was found in built-up (Fig. 8) as well as in agriculture class. On the other hand, a negative growth rate was observed in wetland and vegetation classes between 1996 and 2008. During 2008–2020, a significant increase of 0.74 was seen in built-up, and a decline of −0.40 in the growth of agriculture was ascertained. Built-up has been the most prominent growing class, while wetland and vegetation class reduced continuously.

Table 4 Change matrix, 2008–2020

	2020						
	Class name	Wetland	Vegetation	Built-up	Agriculture	Others	Total
2008	Wetland	**9292.59**	779.94	4579.56	3361.77	723.6	18,737.5
	Vegetation	1265.49	**5697.81**	8545.59	8106.57	1799.19	25,414.7
	Built-up	1298.97	4430.88	**57,966.8**	7083.9	3038.31	73,818.9
	Agriculture	2794.68	6244.74	15,535.3	**30,035**	2726.64	57,336.4
	Others	309.51	378.81	3618	413.64	**2831.04**	7551
	Total	14,961.24	17,532.18	90,245.25	49,000.88	11,118.8	182,858

As shown in Fig. 9 that AWGR was found negatively because, in Panihati, Konnagar, Uttarpara, Kamarhati, North dumdum, Baranagar wards, and Howrah municipal corporations area in 2008 and the Mahastala wards and East Kolkata Wetland in 2020 majorly transformed wetland into built-up and agriculture area. The AVGR also showed a negative growth rate because deforestation was carried out in Barasat, Mahastala, Budge Budge, Pujali wards, and in rural areas of Howrah, Hooghly, and South 24 Parganas due to migration, increasing population, new planning of town area and creation of different recreation center. The ABGR shows that the maximum positive growth rate was found in Bansberia, Kalyani, Sonarpur/Rajpur wards in 2008, while the highest rise in 2020 was seen in Uluberia, Barasat, Madhayamgram, Baruipur, Maheshtala wards, and the north part of Howrah along the Madhayamgram-Barasat road and the NH16 by joining the Uluberia wards to join the NH19 near Calcutta chord line west. Built-up areas act as either positive or negative but the unplanned growth has constantly created a negative pressure on other areas. The AAGR showed positive growth in 2008 because the vegetation and wetland area of Uluberia, Kalyani, Gayeshpur wards, and the non-municipal area of Howrah, Hooghly, South 24 Parganas, and the Nadia district transformed into an agricultural area, but by 2020, it manifested the negative rate as the agriculture area in Baidyabathi, Uluberia wards, Howrah municipal corporation and all along with the expansion of Kolkata Urban Agglomeration captured by the built-up. The AOGR also indicated positive growth because of the metro route and fly over construction, playground, and an increase in bare land. The concern related to shrinkage of wetland and vegetation area simultaneously with a great increase in built-up has raised a question on planning. Since landscape transformation is an ongoing process, if it is not monitored and regulated properly, then it may damage the environmental sustainability of the study area.

5 Discussions

The land use/land cover in Kolkata Urban Agglomeration changed drastically after independence; millions of refugees (about 4 million) migrated from Bangladesh

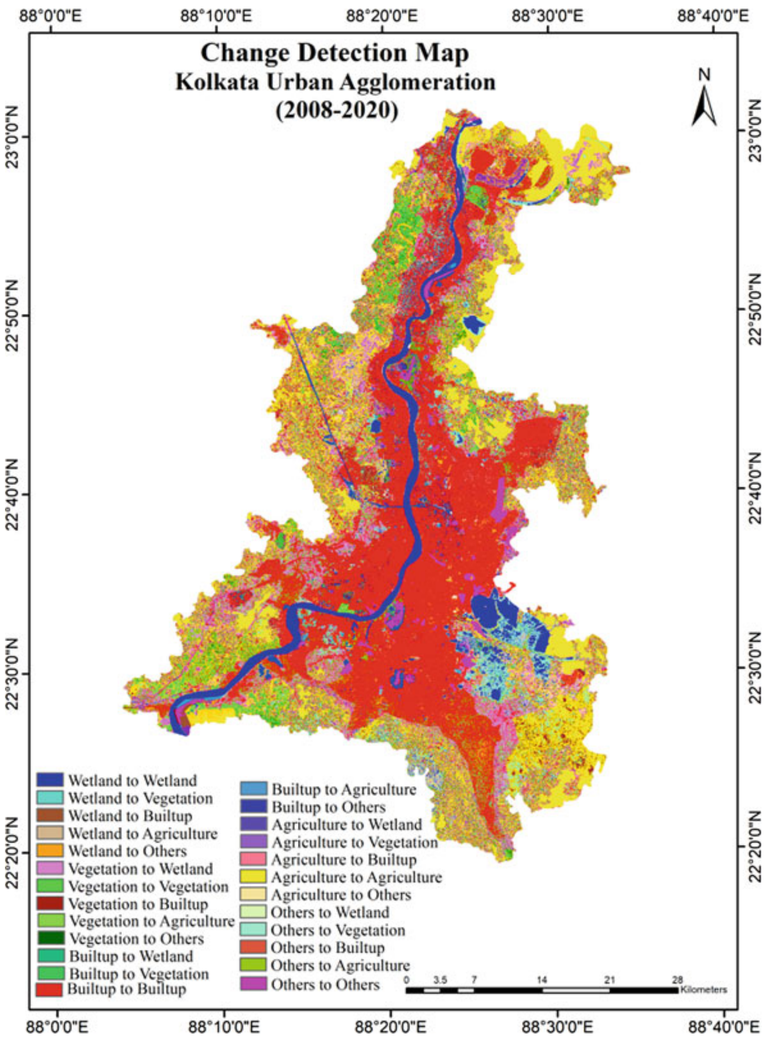

Fig. 7 Change detection, 2008–2020

to West Bengal between1946 and 1971. As Kolkata is the hub for employment, education, industries, and other economic activities that attracted people from towns, cities, and the other districts as well as neighboring states and countries in India (Chatterjee 1990; Roy 2003; Mitra et al. 2012). Initially, the agriculture area showed a trend of positive growth, but with time, it started decreasing and there could be a possibility in further reduction in the area might be caused by urban expansion and other anthropogenic activities.

Table 5 Change matrix, 1996–2020

	2020						
	Class name	Wetland	Vegetation	Built-up	Agriculture	Others	Total
1996	Wetland	**9167.04**	1842.12	10,378.1	5626.71	1470.42	28,484.4
	Vegetation	1438.83	**7191.81**	11,571.5	9000.99	2121.57	31,324.7
	Built-up	1699.74	3511.98	**51,376**	7092.81	2844	66,524.5
	Agriculture	2377.62	4538.43	14,769.8	**25,961.8**	2477.34	50,125
	Others	216.63	348.12	1961.19	981.81	**2168.28**	5676.03
	Total	14,899.86	17,432.46	90,056.59	48,664.12	11,081.6	182,135

The present research work manifested major changes in vegetation and wetland with a net decrease of 13,892.13 ha and 13,584.26 ha, respectively, in the last twenty-four years, while on the other hand; built-up grew by 23,531.98 ha. The wetland area has been shrinking due to haphazard built-up growth, agriculture activities, industrial sector, and other developmental activities, e.g., New Town city and the Barrackpore-Kalyani expressway (Majumdar and Sivaramakrishnan 2020). The New Town city plan vanished the area of both agriculture and wetland, it had been estimated that 304 hectares of land decreased within 7 years (Sardar 2013). About half of the wetland area shrunk from 1996 to 2020 in Kolkata Urban Agglomeration (Choudhary et al. 2017). The unplanned growth of urban agglomeration has been engulfing the wetland and vegetation in KUA. If wetlands, vegetation area, and agricultural land is not managed properly then these will be degraded soon.

The past studies also indicated that the LULC area transformed rapidly because of industrial development (Maity et al. 2020), tremendous pressure from increasing population growth (Mondal and Sahoo 2021; Mandal et al. 2019), climate change (MAS 1999), and the haphazard growth of built-up areas (Govind and Ramesh 2019) in most of biggest cities. The vegetation and wetland areas in the interior part encroached slowly and rapidly captured the peripheral areas due to the development of built-up classification (Naikoo et al. 2020) in the Delhi NCR region. In their work, Chamling and Bera (2020) noted that major encroachment found in the natural landscape due to man-made activities in Bhutan–Bengal foothill. In the Jhargram district of West Bengal, the similar outcome (Kayet et al. 2019) was seen, with an increase in built up category but a loss in agriculture and vegetation area. These results have determined the negative impact of built-up areas on non built built-up areas of the research area. Therefore, the huge industrial development, agriculture, and economic growth have been the key factor to transform the LULC pattern in the study area.

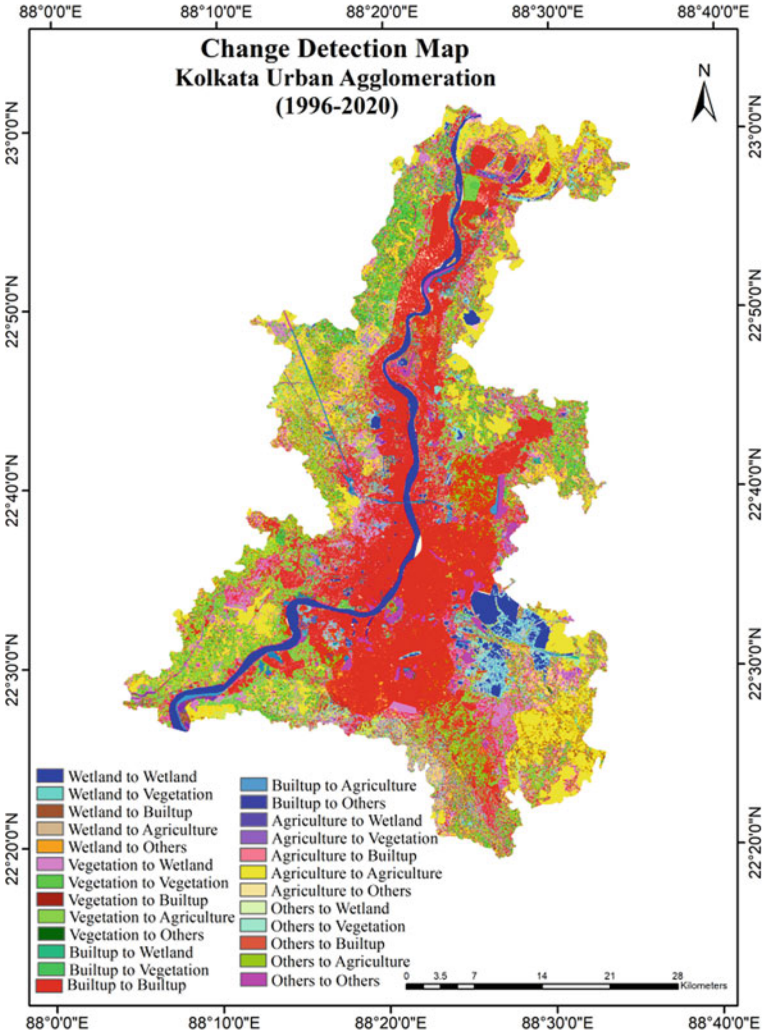

Fig. 8 Change detection, 1996–2020

6 Conclusions

This study explored the spatio-temporal change in KMDA during 1996–2008 and 2008–2020 that manifested drastic transformation in LULC, the positive growth occurred in built-up areas whether significant decline observed in vegetation and wetland classes. The built-up area expanded toward the peripheral areas in open land, agriculture areas, wetland area, and along the roadways from 1996–2020. Despite several policies by the state government and non-governmental organizations to protect the wetland and vegetation area, the haphazard built-up growth put great

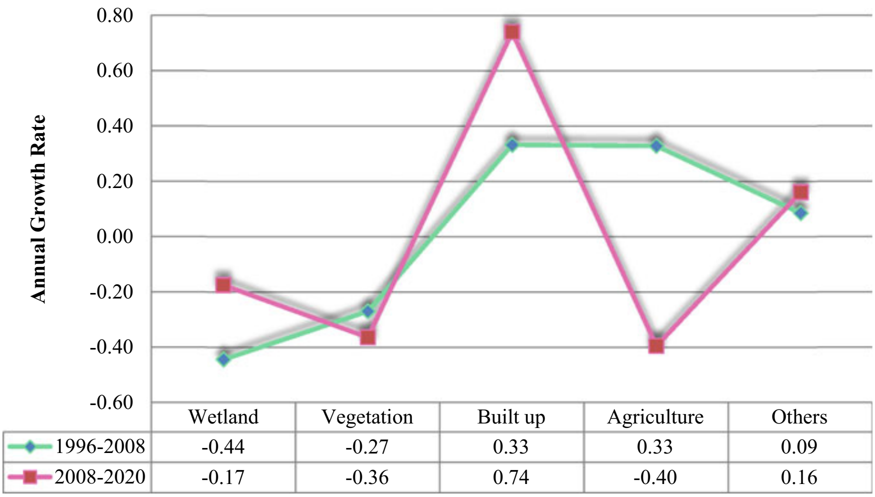

Fig. 9 LULC Growth Rate, 1996–2020

pressure on the environmental health of the study area. If this trend continues, there will be a huge problem that may occur shortly. It could be asserted that there is a need to protect the environment's health and services by providing alternative works such as wetland fishing cultivation, which is more promising because it delimits encroachment from other land use classes and also provides economic support, while constant monitoring in the study area with the help of local communities, organisations, and municipalities could help to minimize the further degradation.

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Vulnerability Assessment of COVID Epidemic for Management and Strategic Plan: A Geospatial-Based Solution

Gouri Sankar Bhunia

Abstract Due to the regular increase of COVID, there is a need to devise a tool for district-level planning and prioritization and effective allocation of resources. Based on publicly available information, this analysis is being conducted to establish a vulnerability index based on population and infrastructural characteristics to classify vulnerable districts in West Bengal. A composite index of vulnerability at the district level is calculated based on seven indicators across knowledge deprivation (literacy rate), provisioning deprivation (lack of sanitation facility, lack of electricity and safe drinking water), and population density. Pearson correlation test was used to determine the correlation between vulnerable indicators and COVID incidence. A geographically weighted regression index was used to perform the vulnerability index. To measure both domain-specific and overall vulnerability, the percentile ranking approach was used and geographically presented results in districts. The adjusted R^2 is calculated as 0.87 with the Akaike Information Criterion of 111.19. North 24 Parganas, Hooghly, Kolkata, and Howrah, located in the southeast part of the state, were found to have high overall. While the aim of this analysis was not to estimate a district's risk of infection, we found correlations between vulnerability and the current incidence rate of COVID intensity at the district level. The suggested index seeks to help planners and decision-makers coordinate vaccine allocation regions efficiently and enact risk reduction policies for improved preparedness and reaction to the epidemic of COVID.

Keywords COVID · Pearson's correlation · Geographically weighted regression · Vulnerability index · Management strategy

1 Introduction

Coronavirus disease 2019 has been infected with coronavirus 2 (SARS-CoV-2) extreme acute respiratory syndrome which is primarily responsible for causing

G. S. Bhunia (✉)
Independent Researcher, Kharagpur, West Bengal, India
e-mail: rsgis_gouri@rediff.com

H. Sajjad et al. (eds.), *Challenges of Disasters in Asia*, Springer Natural Hazards,
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mayhem in the entire human society (Franch-Pardo et al. 2020). With more than 11.25 million confirmed cases and more than 24,97,514 deaths reported globally, there are significant concerns about the public health, social and economic impacts of the virus, especially on susceptible and impoverished communities, as well as on fragmented healthcare systems in low- and middle-income nations (https://covid19.who.int/; Budd et al. 2020). Asia's densely populous nations, including India, Bangladesh, and Pakistan, are highly susceptible to this disease due to high population densities, inadequate healthcare services, and poverty (Kanga et al. 2020). More than 11,077,991 confirmed cases have been registered in India as of February 26, 2021, of which about 156,069 (1.41%) were alive, 10,760,401 (97.13%) recovered, and 156,950 (1.41%) died (https://www.covid19india.org/).

In India, state governments are preparing risk-informed lockdowns by defining areas of differing levels of intensity, using the criteria known to control the infectiousness of COVID-19 to date. In addition, unique hypothesized criteria like BCG vaccinated individuals and women are resistant to the survivability of this infection, which determines the community's resistance to this disease pandemic. The total number of doses of the COVID-19 vaccine given to clinicians and frontline staff in the country has surpassed 1.3 cr. The COVID-19 vaccine will be applied to people over 60 years of age and those over 45 years of age with comorbidity from 1 March onwards. Since the weakest members of the community would suffer the impact of an epidemic-induced economic shock, it is crucial to recognize the social status of a nation while designing a vulnerability index. Moreover, the propensity of a population to obtain medication and handle an epidemic is contingent on quick and reliable access to well-equipped healthcare services, which should be included in the risk index. There are many epidemiological variables that may place a population at risk of a higher COVID-19 infection incidence rate and mortality, and therefore should be included in the vulnerability index.

Indeed, traditional mapping and, more specifically, geographic information systems (GIS) have long been regarded by health practitioners as essential resources for monitoring and fighting contagion (Sarkara and Chouhan 2021). The pandemic of COVID-19 is full of uncertainties and most of them have a geographical dimension that leads to a regional and effectively mappable picture of the concepts (Ye et al. 2021). Consequently, the research needs of health science provide the ability to interpret the COVID-19 phenomenon across variables of numerous types, its geographical analysis and stochastic aspects, its spatial impact on decision-making and daily life, and predictive analytics of the disease's evolvement (Acharya and Porwal 2020). In order to track the spread of the virus, assess the risks, manage services, and target rebuttals, efficacious epidemiological surveillance is based on common geospatial data (Juergens 2020).

In this sense, an effort was made to provide an instrument for district-level preparation and response to the West Bengal COVID-19 epidemic. To rank each district of West Bengal through knowledge deprivation (literacy rate), provision deprivation (lack of sanitation facilities, lack of electricity, and clean drinking water), and population density, a series of indices were measured to rank each district of West Bengal, rendering them susceptible to a natural disaster in general, as well as the epidemic of COVID-19.

2 General Description of the Study Area

West Bengal state is extended between 27°13′15″ and 21°25′24″ north latitudes and 85°48′20″ and 89°53′04″ east longitudes. There are 23 districts and 5 divisions in West Bengal. The state also shares Bangladesh, Bhutan, and Nepal's international boundaries. It is the fourth-most populated state with over 91 million people and the fourteenth-largest state by population in India. It is also the world's seventh-largest country subdivision, with a gross area of 88,752 km^2. Kolkata, the state's capital and largest city, is India's third-largest metropolitan agglomeration and seventh-largest city. After Kolkata, Asansol in West Bengal is the second-largest city and metropolitan agglomeration. Siliguri is a city of economic importance, geographically situated in India's northeastern Siliguri Corridor (Chicken's Neck). The climate of West Bengal ranges from dry savannah in the southern part to humid subtropical savannah in the north. Although the summer is noted for excess humidity in the delta zone, the western highlands, like northern India, experience a dry summer. West Bengal receives the Indian Ocean monsoon's Bay of Bengal branch, which travels southeast to northwest. The southern portion of West Bengal can be separated into two regions from a phytogeographic point of view: the Gangetic plain and the Sundarbans' littoral mangrove forests.

3 Materials and Methods

3.1 Data Collection and Database Creation

The data for this study came from India's Ministry of Health (MoH), which is in support of tracking COVID-19 on a regular basis at the local level throughout the country. The number of cases, death, and active cases was documented up to February 2021. Socioeconomic data at the district level was collected from the website and mid-year population. Spatial units for this analysis were districts. A shapefile was created within the GIS environment and ArcGIS Desktop 9.5 was applied to associate the COVID cases data. Based on available current databases from the global administrative areas database, an administrative boundary map of district borders in shapefile format was prepared and revised. A variety of secondary datasets from the Ministry of Human Resource Development, Government of India, were used for this research. Various reports, such as the 2011 Census and the District Level Household Survey Report-4, were used to collect district-level data for the indices.

3.2 Variable Selection

A very crucial component of vulnerability evaluation is variable demarcation. There is a variety of evidence available on the initiating mechanisms that made the COVID-19 pandemic more vulnerable to a particular demographic condition. Many researchers put more emphasis on social and environmental influences that can have a direct influence on COVID-19 disease outbreaks (Tsai and Wilson 2020; Sarkara and Chouhan 2021). Since the essence of the COVID-19 outbreak is such that both the rate of transmission and infection-related mortality are based on population dynamics, demography should be included in a risk index. Since high population density will contribute to rapid group spread, population density is taken into account. The largest number of deaths is reported among the underprivileged communities, as shown by the percentage of households with low wages, people belonging to the backward class, Scheduled caste Schedule tribe, and low workforce participation rate. Three aspects of human deprivation have been chosen based on data availability: (i) Knowledge deprivation, (ii) Healthcare deprivation, and (iii) Provisioning deprivation. Knowledge deprivation is the weighted sum of the overall rate of illiteracy and the proportion of primary-level children not passed to the upper primary level (Dutta 2017). Healthcare deprivation is primarily the percentage of non-institutional deliveries. The arithmetic mean of (i) the proportion of households without access to electricity, (ii) the proportion of households without access to latrine facilities within the property, and (iii) the proportion of households without access to clean drinking water is regarded as provisioning deprivation.

3.3 Geographically Weighted Regression (GWR)

QGIS version 2.3 is used for calculation, exploratory analysis, mapping, and visualization. The incidence rate of COVID cases by district level from up to February. Such statistical values were integrated as non-spatial data into the designed GIS vector polygon map. To model spatially varying relationships, a geographically weighted regression (GWR) analysis is performed (Mitchell 2005). As explanatory variables, multiple demographic and health factors, such as knowledge deprivation (literacy rate), provisioning deprivation (lack of sanitation facility, lack of electricity, and safe drinking water), and population density were identified and chosen for the study. The rate of occurrence as a predictive variable was used. The kernel bandwidth is demarcated to determine the distance above which neighbors' local projections are no longer affected by them. A regional surface of models is generated with related goodness-of-fit statistics and spatial parameters are estimated such as R-square, standard error, and t-values. The output illustrates potential data relationships, exceptions for help finding or geographic hotspots, and offers detail on the essence of the processes being examined.

3.4 Statistical Analysis

A descriptive characteristic (mean, median, standard deviation, kurtosis, and skewness) of demographic parameters and COVID cases were calculated. The analysis was performed in Microsoft Excel 2010. An exponential linear relationship was calculated with the dependent variable being the incidence rate of COVID cases and independent variables being demographic variables. A preliminary Pearson correlation coefficient (r) was undertaken to select covariates with the dependent variable (COVID incidence rate) and independent variables (knowledge deprivation, healthcare deprivation, and provisioning deprivation). All the statistical analysis was performed at a <0.05 significance level.

4 Results

Up to February 2021, a total of 574,716 COVID cases were recorded. The average number of COVID cases per district was calculated as 24,884 with a standard deviation of ±33,049.62. However, the maximum number of cases were recorded from Kolkata (128,491), followed by North 24 Parganas district (122,437) and South 24 Parganas district (37,087). The lowest number of cases were observed in Kalimpong district (2229), followed by Jhargram district (3042) and Uttar Dinajpur district (6651). The average number of cured cases was estimated as 24,259 ± 31,994.8. The average active cases were estimated as 181 (Table 1). The highest number of active cases were recorded from Kolkata (1107), followed by North 24 Parganas district (1021) and West Barddhaman district (275). The least number of active cases were documented from Alipur Duar (12) and Dakshin Dinajpur (14). The average incidence rate of West Bengal State is calculated as 5.36 per 1000 population. The highest incidence rate was calculated for the Kolkata district (28.57/1000 population), followed by North 24 Parganas (12.23/1000 population), and Darjeeling (9.95/1000 population), located in the southeast and north of the state (Fig. 1a). The lowest

Table 1 General characteristics of COVID cases in West Bengal (upto 18th February, 2021)

COVID/Descriptive statistics	Mean	Standard error	Median	Standard deviation	Kurtosis	Skewness
Cases	24,884.3	6891.32	12,669	33,049.62	6.90	2.74
Cured	24,258.78	6671.38	12,506	31,994.8	6.89	2.73
Active	180.87	59.83	98	286.92	7.46	2.86
Death	444.65	163.52	149	784.18	7.12	2.75
Incidence rate/1000 population	5.36	0.81	4.20	3.88	5.43	2.19
Mortality rate/1000 population	0.09	0.03	0.05	0.14	14.72	3.64

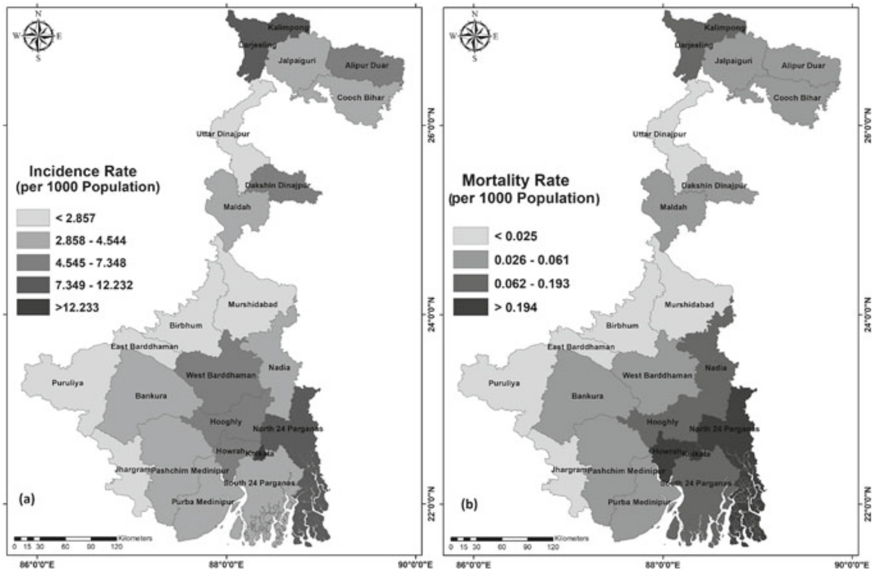

Fig. 1 Incidence rate **a** and mortality rate **b** of COVID cases in West Bengal (Up to February 2021; *Source* https://www.covid19india.org/)

incidence rate was calculated from Puruliya (1.729/1000 population), followed by Bankura (2.212/1000 population), and Birbhum (2.463/1000 population), distributed in the west and central part of the state. The highest mortality rate was calculated for Kolkata and the minimum mortality rate was calculated for Puruliya. The high mortality rate of COVID cases was observed in the south, southwest, and north of the West Bengal (Fig. 1b).

Table 2 shows the descriptive characteristics of vulnerable factors of COVID cases. In the study area, the average population density was calculated as 1685.43 ± 1575.33. However, the maximum population density was calculated for Kolkata (7024 per km^2), followed by North 24 Parganas district (4306 per km^2) and Darjeeling (3306 per km^2). The lowest population density was calculated for Puruliya (370 per km^2), followed by Bankura (468 per km^2) and Birbhum (523 per km^2). The highest index of knowledge, index of health service, and index of provisioning deprivation were calculated for Kolkata, followed by North 24 Parganas and Darjeeling. Moreover, the lowest value of the deprivation index was calculated for Puruliya, followed by Bankura and Birbhum (Table 2). The highest value was calculated.

The calculated Pearson's correlation test between population and density and COVID incidence rate showed a strong positive correlation of 0.45 ($P < 0.05$). Pearson's correlation test between COVID incidence rate and knowledge deprivation, healthcare deprivation, and provisioning deprivation was calculated as −0.55, −0.56, and −0.76, respectively. Figure 2 shows the exponential correlation between COVID incidence and deprivation index of knowledge, health service, and provisioning. The exponential relations between COVID incidence rate and population

Table 2 Descriptive characteristics of vulnerable factors of COVID

Predisposing factors	Mean	Standard error	Median	Standard deviation	Kurtosis	Skewness
Population density (per km^2)	1685.43	328.48	1054.00	1575.33	5.15	2.15
Index of knowledge deprivation	0.22	0.01	0.22	0.05	−0.12	−0.13
Index of health service deprivation	0.22	0.02	0.22	0.10	0.57	0.49
Index of provisioning deprivation	0.39	0.03	0.40	0.14	0.34	−0.27

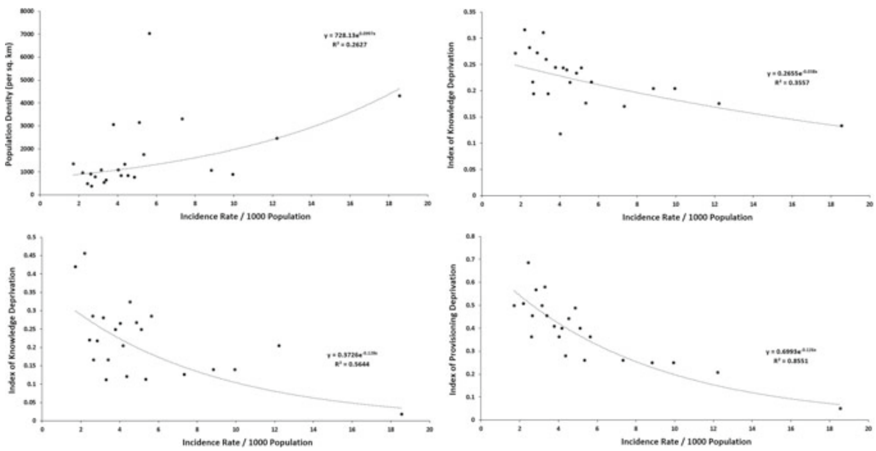

Fig. 2 Correlation between causative factors and COVID incidence rate

density, knowledge deprivation, healthcare deprivation, and provisioning deprivation were estimated as 0.26, 0.35, 0.56, and 0.85, respectively, referred to a strong relationship with COVID incidence.

The summary statistics of GWR are represented in Table 3, with an adjusted R^2 of 0.7 and Akaike Information Criterion of 111.19. Figure 3 showed the COVID vulnerable index map of West Bengal state at the district level. The results also

Table 3 Summary statistics of geographically weighted regression

Bandwidth	Residual squares	Effective number	Sigma (σ)	AICc	R^2	Adjusted R^2
4.11	66.11	6.79	2.02	111.19	0.90	0.87

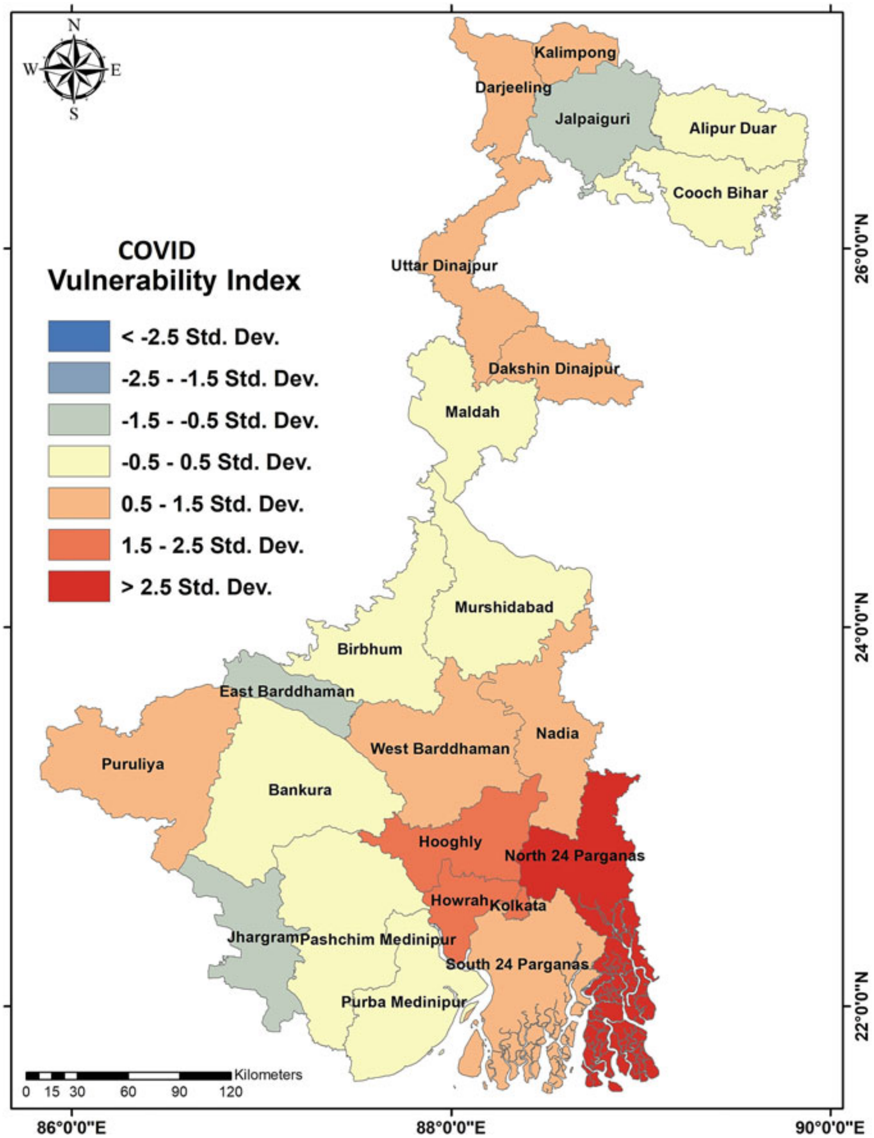

Fig. 3 COVID 2019 vulnerability index map

showed the very high vulnerability district is considered as North 24 Parganas, Hooghly, Howrah, and Kolkata. The high vulnerable district was considered as South 24 Parganas, Nadia, West Bardhamann, Puruliya, Kalimpong, Darjeeling, Uttar Dinajpr, and Dakshin Dinajpur. The medium vulnerable district was identified as Purba Medinipur, Paschim Medinipur, Bankura, Alipur Duar, Cooch Bihar, Maldal, Mushidabad, and Birbhum. The low vulnerable district was considered Jalpiguri, East Bardhamann, and Jhargram.

5 Discussion

Owing to the lack of a vaccine or appropriate treatment, several forms of the disease will continue to influence people around the world, even having a major economic impact. Effective strategies and the appropriate data are required to minimize attempts to curb the COVID-19 outbreak and control its far-reaching effects. In this report, the District Vulnerability Index is intended to help government efforts to respond effectively to West Bengal's rapidly evolving COVID-19 epidemic. This data will be used by planners to identify disadvantaged communities and offer assistance in planning for, as well as minimizing and reducing, the health and socioeconomic impacts of COVID-19.

The vulnerability index can be discussed from many angles. The vulnerability index derived through GWR is simple, additive, and reliable. The results of the study show that North 24 Parganas, Hooghly, Howrah, and Kolkata districts have high vulnerability. This vulnerable district has a poor index of knowledge deprivation, healthcare deprivation, and provisioning deprivation. There are a large number of low-wage workers in West Bengal who travel across the country. Due to a stop in nearly all commercial operations during the national lockdown, when lockdown controls are relaxed, the state is seeing millions of these migrant workers return to their districts of origin (Acharya and Porwal 2020). The bulk of these individuals came from vulnerable states like Delhi, Uttar Pradesh, and Bihar, with Madhya Pradesh, Punjab, Rajasthan, Uttarakhand, Jammu and Kashmir, Hyderabad, and Chennai.

There are certain drawbacks, considering the utility of the index. Ideally, measuring the index at the level of a block or village would be feasible. However, at the micro-level, several significant variables used to describe vulnerability were not available. This study is, however, confined to the district level. In order, to improve the map, environmental criteria and other demographic characteristics must be included. Finally, the data used in this analysis is 5 years old and may not well have captured uncertainty in districts where rapid changes have occurred to date.

6 Conclusion

Combating a recently emerged pandemic is a daunting challenge. GIS tends to be valuable decision-making instruments in cases where evidence is not organized and accessible in such a manner that it can be used to examine the impact of socioeconomic influences on a phenomenon. An understanding of real-world conditions can be provided by vulnerability evaluation using a GWR. Socioeconomic backward districts were illustrated by the vulnerability ranking. These regions will face more serious problems with the COVID-19 pandemic because of their geographic difficulties. Depending on the underprivileged demographic group, these districts should be given higher priority. Finally, for a more detailed result, more vulnerable factors are to be considered.

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Adaptation

Auto-generated Gravity Canal Routes for Flood Mitigation and Groundwater Rejuvenation: A Study in Damodar–Barakar River Basin, India

Soumita Sengupta, Sk. Mohinuddin, and Mohammad Arif

Abstract Diversion of excess surface runoff is essential predominantly for the potential surface runoff zones causing inundation of the area and its adjacent sides. This eventuality can be resisted if the surplus water can be transported by some means to the groundwater depletion zones receiving scarce surface runoff. The mode of transporting the excess surface runoff and identifying the best suitable site for its outfall are significant challenges. The present study introduces gravity canals. This research aims to divert the excess surface runoff by a canal routing model (CRM) and discharge the transported water to suitable groundwater recharge zones by performing the site suitability model for canal outfall. The geographic information system (GIS) associated with various supportive tools was used to prepare these models. The criteria considered in CRM were digital elevation model (DEM), land use/land cover (LU/LC) and lineament length density, and for the site suitability model for canal outfall, the criteria were digital elevation model (DEM), land use/land cover (LU/LC), lineament length density and groundwater depth fluctuation. Analytical hierarchy process (AHP) was used for multi-criteria decision making (MCDM) in the GIS environment for both models. The study revealed three suitable gravity canal routes to transport the surface water and three suitable groundwater recharge zones. This research provides a vital scientific contribution to planners, decision-makers and hydrologists to identify the groundwater depleted zones and find the best path for groundwater rejuvenation.

Keywords Canal routing · Site suitability · Canal outfall · Analytical hierarchy process · Groundwater rejuvenation · Gravity canal

S. Sengupta (✉) · Sk. Mohinuddin
Department of Remote Sensing, Birla Institute of Technology, Mesra 835215, Jharkhand, India
e-mail: soumitasengupta@gmail.com

M. Arif
Department of Geography, Central University of Jharkhand, Ranchi 835222, Jharkhand, India

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1 Introduction

Natural or anthropogenic reasons, mainly excessive rainfall result in the overflowing of surface water bodies which inundate the adjacent areas (Ghosh 2013; Ghosh and Guchhait 2016; Mistri et al. 2014). This impacts most of the time the economy, society and environment of a country. The magnitude of damage varies from basin to basin (Chandra 2003; Ghosh 2011). On the other hand, groundwater depletion has become an issue of concern, as living beings largely depend on groundwater resources for drinking, irrigation and industrial uses (Mahato et al. 2017). Depletion of this resource also has an impact on climate, as in many areas of the world vegetation sustenance is dependent on this resource (Boulton et al. 2006). Therefore, rejuvenating groundwater by checking surface runoff has become essential. However, it is practised across the globe through artificial recharging mainly from in situ rainfall-runoff (Igboekwe et al. 2011; Mukherjee 2016). That is often not efficient due to the small catchment area. Groundwater recharge can also be facilitated by channelling the surface runoff from nearby areas, particularly where excessive surface runoff causes flooding (Tiwari et al. 2017). If such excessive surface runoff is diverted to groundwater depleted nearby areas, it may serve purposes like minimizing flooding, rejuvenation of groundwater and storing water for critical uses (Sinha and Rao 1985). However, channelizing excess surface runoff to nearby areas should be routed optimally. So, to obtain the optimum route, factors like cost, topography elevation and land use/land cover (LU/LC) can be considered to use as input in the geographic information system-based (GIS) model. These factors can be generated with the help of relevant satellite data.

Several flood-related studies have revealed, i.e., Indrawati et al. (2018) show that the diversion canal performs well in terms of lowering water levels and flood discharge in the Ciliwung river basin. Another researcher is analysing land-use changes and climate assessment in the upper Ciliwung river basin using HEC-HMS modelling (Rafiei Emam et al. 2016). Studies have been attempted to find optimum routes for transporting excessive surface runoff water in the most suitable outfall locations—low-lying areas in groundwater-depleted zones using the analytical hierarchy process (AHP), a multi-criteria decision-making process in the GIS environment. A gravity canal can be the most economical way of transporting water from one place to another. In selecting the optimum path for a gravity canal only two aspects have been considered: the cost and the slope (Pilar and Collischonn 2000). The gravity canal route optimization can be improved by considering more parameters such as land use/land cover (LU/LC), drainage network, topography elevation and shortest route. The present study proposes a GIS-based model like the canal routing model (CRM) to transport the excess surface runoff water considering the parameters: topographic elevation, LULC including infrastructure, shortest route and drainage network. We also attempt to identify suitable corresponding outfall locations through the site suitability model for canal outfall. Both the models have been trained to work in an ArcGIS environment.

2 Materials and Methods

2.1 Study Area

The study was carried out on the upper part of the Damodar–Barakar river basin situated in Jharkhand state, India (Bhattacharyya 2011). The region has a total geographical area of 17,059.7 km^2 within 23° 40′ N to 24° 20′ N latitude and 85° 0′ E to 86° 40′ E longitude (Fig. 1). The elevation in the basin varies from 65 to 1374 m above mean sea level (MSL). The area receives an annual average rainfall of 1200–1250 mm. The temperature of this region varies between 40 and 42 °C in summer and 23 and 26 °C in winter (Chakraborty 2011). The population of this region is 2.6% of India. The basin is suffering from a shortage of agricultural land due to the rapid growth of urbanization (Singh and Singh 2012). The region comprises five important reservoirs: Tilaiya, Konar, Tenughat, Maithan and Panchet which are affected by heavy siltation resulting in reduced storage capacity (Shet 2016; Sarkar 2016). During monsoon rainfalls, the surface runoff from the upper catchment hills quickly descends carrying a massive amount of silt that gets deposited in these reservoirs (Kumar et al. 2016; Ganga Flood Control Commission 2015). As a result, the storage capacity of these reservoirs gets reduced and a huge volume of water spills out from the reservoirs. This surplus water gets drained into the downstream areas (Ghosh and Mistri 2015; Ghosh 2014). On the other hand, water scarcity has become another vital issue in some areas where overpumping is common, especially in significant food-producing zones (Jharkhand State Water Policy 2011; Central Ground Water Board 2017). Therefore, the water table in some parts of the river basin experiences a falling trend (approximately 0.4 m per year) imposing people to bore deeper (Singh and Singh 2012; Singh and Verma 2015).

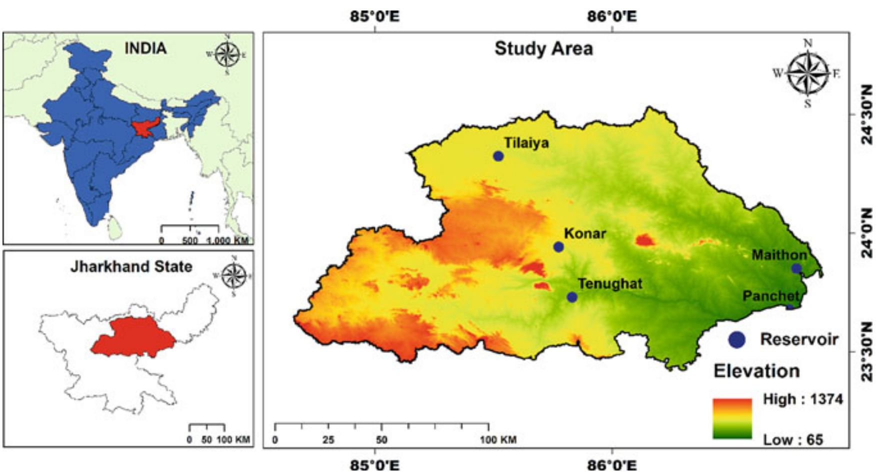

Fig. 1 Hierarchical location map of the study area

Table 1 Details of the satellite data used in the study

Sensor/Satellite	Year of acquisition	No of bands	Spatial resolution (m)
SRTM	2008	1	30
LISS-IV	2018	3	5.8

2.2 Data

Digital elevation model (DEM), land use/land cover (LU/LC) and lineament map were three essential parameters which canal routing model (CRM) necessitates for automatic detection of an optimum path over a surface to channelize the surface runoff and an additional groundwater data was considered for site suitability model for canal outfall to identify the suitable outfall locations for the delineated canals.

Shuttle Radar Topographic Mission (SRTM) DEM of 1 arc second spatial resolution was downloaded from the site (U.S. Geological Survey) to generate the slope map of the area. RESOURCESAT-1 LISS-IV imagery (2018) of 5.8 m spatial resolution and swath width 24–70 km, provided by Regional Remote Sensing Center (RRSC-E) East of Indian Space Research Organization (ISRO) was used to derive the necessary LU/LC for the proposed area of interest. Lineament map showing the lineaments of Jharkhand state, provided by Regional Remote Sensing Center (RRSC) East of Indian Space Research Organization (ISRO) was used in the study for effective watershed management and block-wise bore well and dug well data of 25 years (1979–2014) was downloaded from the site (India Water Resources Information System n.d.) for water table variability analysis. The details of satellite data are provided in Table 1.

2.3 Generation of Standard Maps Using GIS Techniques

2.3.1 Generation of Standard LU/LC Map

Land use/land cover (LU/LC) map was prepared by performing a supervised classification technique with an overall classification accuracy of 90.00% and overall kappa statistics of 0.8716. The LULC map was classified into nine classes: built-up, cropland, dense forest, open forest, fallow, mines, open industries, water bodies, and sand.

2.3.2 Generation of the Lineament Density Map

To generate the lineament length density map representing the total length of lineaments in a unit area, ArcGIS software was used to adopt a line density tool that computed the lineament length density considering the following equation (ESRI

2017) (Eq. 1):

$$L_d = \frac{\sum_{i=1}^{i=n} L_i}{A} \tag{1}$$

where L_i is the length of individual lineament in the calculated unit area and A is the calculated area (Zhumabek et al. 2017). This line density tool computes the density of linear features in each cell of the exit grid. Density is computed in length per unit area. The tool works while considering a radius equal to a search radius around the centre of each grid cell. Each lineament length inside this area is summarized and the outcome is divided by the circle area.

2.3.3 Generation of the Average Groundwater Depth Map

To prepare the average groundwater depth map, block-wise bore well and dug well data were collected, ensuring uniform distribution of well locations. Data for 86 well locations were selected and downloaded for analysis purposes. These data were arranged in pre-monsoon and post-monsoon format and an average of 25 years of water table depth was evaluated for effective water table analysis. After evaluating the average groundwater depth of the entire study area, interpolation (Kriging) was performed in the ArcGIS environment to generate a continuous map (raster layer) representing the groundwater table variability.

2.3.4 Generation of the Slope Map

SRTM DEM (1 arc second spatial resolution) was considered input data to generate the slope map. A spatial analysis tool was used to generate the required slope raster in percentage.

2.4 Operation of the Site Suitability Model for Canal Outfall

The standard slope raster, LU/LC, and lineament length density were reclassified into nine classes. The groundwater depth map was reclassified into eight classes. According to their importance, specific weights were assigned to each range for each reclassified dataset. Weights were assigned to each parameter considering the analytic hierarchy process (AHP) proposed by Saaty (2008) where each weight value has its relative importance; hence, this approach necessitates to be deliberate. Integer values in 1–9 scale were provided to each reclassified raster layer signifying the suitability inside every dataset. As the location of the canal outfalls has to be in plain areas, the minimum slope values were given the highest priority in the reclassification procedure (Table 2). Since lineaments are geological structures, they are weaker zone

Table 2 Weights provided to the slope and lineament length density range

Slope value (%)	Lineament length density (per sq. km)	Weight
<2	<1	1
2–4	1–2	2
4–6	2–3	3
6–8	3–4	4
8–10	4–5	5
10–12	5–6	6
12–14	6–7	7
14–16	7–8	8
>16	>8	9

and act as conduits for groundwater movements (Henriksen and Braathen 2005; Gleeson and Novakowski 2009). Hence, high lineament length density zones are most suitable for groundwater recharge. However, the canal outfall location cannot be selected in a high lineament length density zone, as the canal alignment may coincide with a lineament which will eventually increase the chance of canal failure. Therefore, in the reclassified lineament length density map the highest priority was given to the minimum lineament density class. The least priority was given to the maximum lineament density zone (Table 2).

In terms of LU/LC classes, the canal outfall location should be such that it does not coincide with the (i) existing water bodies, (ii) built-up areas, (iii) industrial areas and (iv) sands. But it can coincide with the fallow, mining areas, open forests, dense forests and croplands (Table 3). In the case of groundwater table depth, maximum priority was given to the higher water table depth region (Table 4). Pairwise comparison matrix (PCM) as proposed by Saaty (2008) was evaluated after comparing the selected parameters in a pairwise technique which compared the relative importance of any two input parameters at a stage (Miller et al. 1998) (Table 5). The reclassified raster of the slope, LU/LC, lineament length density and groundwater depth were

Table 3 Weights provided to the LU/LC class

LULC class name	Weight
Mines	9
Crop land	2
Sand	9
Fallow	1
Open industries	9
Dense forest	2
Built up	9
Open forest	2
Water bodies	9

Table 4 Weights provided to the water table depth range

Water table depth (feet)	Weight
<4	9
4–6	8
6–8	7
8–10	6
10–12	5
12–14	4
14–16	3
16–18	2
>18	1

Table 5 The fundamental scale for a pairwise comparison matrix

Importance rank	Definition	Explanation
1	Equal importance	Two criteria enrich equally to the objective criteria
3	Low importance of one over another	Judgments and experience slightly favour one criterion over another
5	Strong or essential importance	Judgments and experience strongly favour
7	Established importance	A criterion is strongly favoured and its dominance established in practice
9	Absolute or high importance	The evidence favouring one criterion over another is of the highest probable order of affirmation
2,4,6,8	Intermediate values between the two adjacent importance or judgments	When an adjustment is needed
Reciprocals	If criteria i has one of the above numbers designated to it when compared with criteria j, then j has the reciprocal value when compared with i	

assigned by 0.08, 0.2, 0.2 and 0.52 weights, respectively (Tables 6 and 7). Consideration of AHP in the model was helpful to detect and compute the inconsistencies and choose the significant factors (Saaty 1980; Garcia et al. 2014). The accuracy of PCM was checked through the consistency ratio (CR) (Eq. 2) (Table 8):

Table 6 Pairwise comparison matrix for multi-criteria decision problems

Criteria	Water table	LULC	Lineament	Slope
Water table	1	3	3	5
LULC	1/3	1	1	3
Lineament	1/3	1	1	3
Slope	1/5	1/3	1/3	1

Table 7 The synthesized matrix for multi-criteria decision-making

Criteria	Water table	LULC	Lineament	Slope	Weight
Water table	0.5356	0.5625	0.5625	0.4167	0.5193
LULC	0.1767	0.1875	0.1875	0.25	0.2004
Lineament	0.1767	0.1875	0.1875	0.25	0.2004
Slope	0.1071	0.0625	0.0625	0.0833	0.0788

Maximum Eigen value (λmax) = 4.0525
Consistency index (CI) = (λmax − n) / (n − 1) = 0.0175 < 0.1
Random index (RI) = 0.90
Consistency ratio (CR) = (CI/RI) = 0.0194 < 0.9

Table 8 Random inconsistency indices (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

$$CR = \frac{CI}{RI} \tag{2}$$

CI refers to the consistency index and RI refers to the random index. The consistency index and random index were also checked (Eq. 3)

$$CI = \frac{\lambda \max - n}{n - 1} \tag{3}$$

where λmax refers to the maximum eigenvalue and n refers to the number of criteria to be compared.

Depending on the order of the calculated matrix provided by Saaty (1980, 2008), the random index was evaluated by the average of the consistency index (Table 8). The value of CR was verified to be less than 0.10 for consistency as a value greater than 0.10 may not provide a logically sound result and indicate inconsistencies (Saaty 2008). After that, each weighted raster layer was combined considering the relative weights through the weighted sum tool in the model. The weighted sum tool is governed by multiplying the selected field values for each input raster layer by a specific weight, and after that, it integrates all input raster layers to produce the output raster (Brewer et al. 2015). The weighted sum approach was suitable for the model as it restricts the rescaling of the reclassified values and preserves the resolution of the overall analysis (Fig. 2).

The generated weighted output raster was then classified into five classes: (i) highly suitable, (ii) moderately suitable, (iii) marginally suitable, (iv) currently not suitable and (v) permanently not suitable.

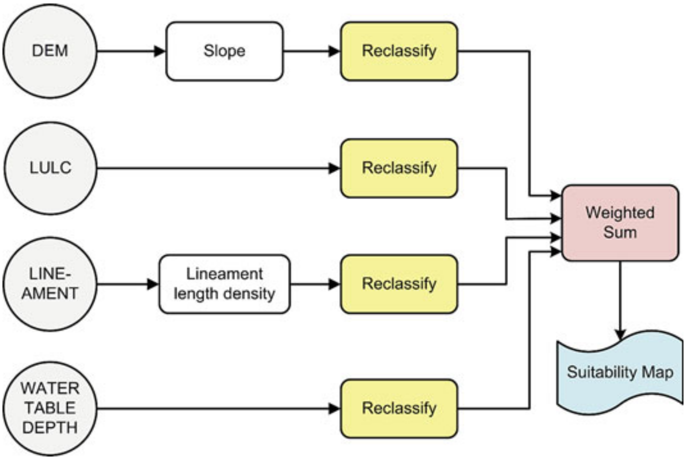

Fig. 2 Flowchart representing the site suitability model for canal outfall

2.4.1 Selection of the Canal Outfall Locations

The selection of the canal outfall locations on the classified weighted output raster was based on the suitability index of the area. Point shapefiles were created in a GIS environment demarcating the locations of canal outfall on the suitability raster of the proposed model. The canal routing model (CRM) used this point shapefile of canal outfalls as primary input data.

2.5 Operation of the Canal Routing Model (CRM)

Considering the weighted and prioritized reclassified rasters of the slope, LU/LC and lineament length density pairwise comparison matrix (PCM) was computed as per Saaty (2008), and thereafter consistency ratio (CR), consistency index (CI) and random index (RI) were checked as per the standard approach proposed by Saaty (1980, 2008). The value of CR was verified to be less than 0.10 for consistency purposes (Saaty 2008). Prioritizing each reclassified raster input was done deliberately. Transportation of water is strongly influenced by the slope parameter. Hence, conveying water through a conduit or canal can be a cost-effective approach if the water is allowed to flow through gravity or in other words, according to the slope of the terrain and considering this principle, weights were assigned to the reclassified slope raster (Table 2). The weights for each class of LU/LC (Table 3) and lineament length density (Table 2) followed the same principle as mentioned in the site suitability model for the canal outfall model (Fig. 3). The details of the AHP are shown in Tables 9 and 10. Researchers showed the combination of the weighted overlay method and AHP is an appropriate approach to solving spatial data's complexity

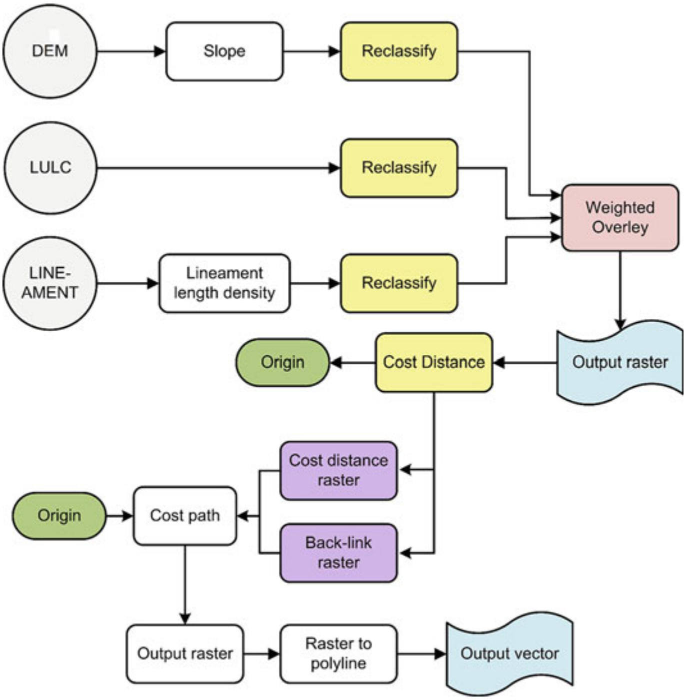

Fig. 3 Flowchart representing the canal routing model

Table 9 Pairwise comparison matrix for multi-criteria decision problems

Criteria	LULC	Slope	Lineament
LULC	1	2	4
Slope	1/2	1	3
Lineament	1/4	1/3	1

Table 10 The synthesized matrix for multi-criteria decision making

Criteria	LULC	Slope	Lineament	Weight
LULC	0.57	0.6	0.5	0.556
Slope	0.285	0.33	0.375	0.322
Lineament	0.143	0.099	0.125	0.122

Maximum Eigen value (λmax) = 3.021
Consistency index (CI) = (λmax − n)/(n − 1) = 0.01 < 0.1
Random index (RI) = 0.58
Consistency ratio (CR) = (CI/RI) = 0.0172 < 0.9

that determines the factors influencing the hierarchy of various input data (Kuria et al. 2011; Parimala and Lopez 2012). Hence, the calculated relative weights were converted into percentages. The total influence for all selected raster layers was checked to be equal to 100% to perform weighted overlay method through weighted overlay tool in the ArcGIS environment. Specific weights (referring 1–9 scale) of each cell of the input raster were then multiplied by the corresponding percentage influence and the subsequent cell values were integrated to produce the weighted overlay output which was further used to compute the cost distance raster.

Canal routing model (CRM) requires two essential input data, i.e., the location of canal origin and canal outfall. To meet these requirements files for canal origins were needed to create. The locations of the canal origins were selected in the vicinity of the reservoirs situated in the study area (but not coinciding with drainages, built-up areas, industries and mining areas) to arrest the reservoirs' surplus water, especially during the monsoons. Thereafter, point shapefiles were created in a GIS environment demarcating the locations of the canal origins. The vector file of canal origins and weighted overlay output were used to generate a cost distance raster using the cost distance tool in the ArcGIS environment. The cost distance tool computed the value at each cell location, which represents the cost per unit distance to move through the cells. The value of every cell location was multiplied by the resolution of the corresponding cell to acquire the total cost while passing through the cells, thus creating a cost raster describing the cost of moving through each cell planimetrically. So, the cost distance tool generated a back-link raster and a cost distance raster. The back-link raster defined the direction or identification of the succeeding cell along the least accumulative path from a cell to reach its least-cost source. In other words, it can be said that the back-link raster helps to determine the route or path to return to the source point through the least-cost path. The cost distance raster identified the least accumulative cost distance over a cost surface to the provided source location was identified by the cost distance raster. The outputs of the cost distance tool and the canal outfall files were further considered as input to calculate the least-cost path from a source point to a destination point and generate an output raster that registers the least-cost path while performing the cost path tool. The output of the cost path tool was converted to line shapefile adopting raster to polyline tool and thereafter the cost-effective gravity canal routes were obtained.

3 Results and Discussion

Analysing the contributing factors, the study discovered that the DEM of the study area revealed an undulated topography with slope values ranging from 2 to >16%. Following a relatively steep gradient, the largest coverage of considerably higher elevation was recorded in the southwest region while the northeast zone was detected with a relatively low elevation value (Fig. 4). Additionally, the derived LU/LC map identified that this region comprised dense forest. Reservoirs like Tennughat and Konar were also seen to be located along with several other drainage networks.

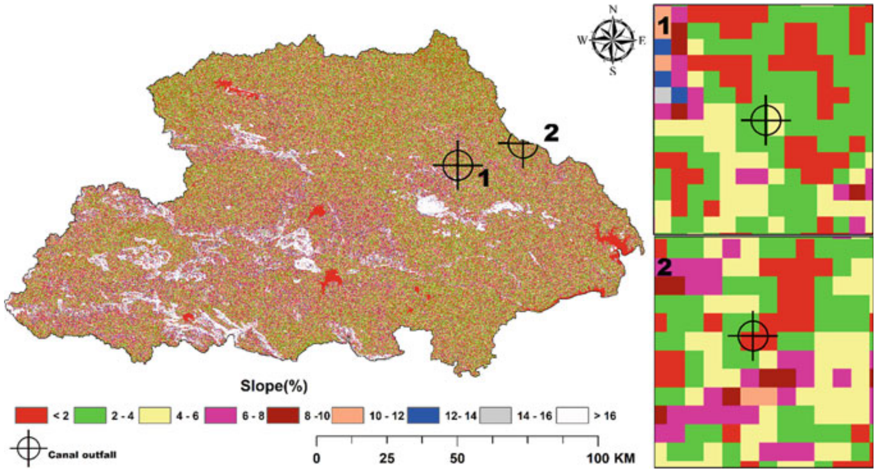

Fig. 4 Slope map representing the canal outfall locations

Mining activities and open industries were also found to be situated in this region (Khurshid 2017). As a result, the land cover type and activities were the underlying factors for the inability to generate any canal route in this zone. Moreover, the south-east zone was detected with a great areal extent of built-ups and mining industries. Water pixels of reservoirs such as Maithon and Panchet, as well as various other streams in the area, were also traced. The cropland and open forest class were seen to be sited in this region acquiring a relatively significant area.

On the other hand, reservoir Tilaiya and different drainage networks garlanded the northeast region of the study area. A noticeable spread of cropland, fallow and open forest was seen in this region. Pixels of open industries and built-ups were detected in some parts of this region but comparatively less amount of dense forest pixels was spotted in this region. The northwest region of the study area was observed with a distinguished land class feature where a reasonable number of pixels indicating fallow class and drainage network was detected but built-up and open industries were discovered to appear as clusters. The open forest class was observed to be in a scattered pattern.

The procured map of lineament length density was able to represent the cumulative length of the lineaments per unit area (sq. km) and the lineament length densities were found to be in the range of <1 to >8 (Fig. 9). The regional areal extend of the lineament length densities are provided in Table 11. The average groundwater depth map generated from well distributed bore well locations gave a clear representation of the groundwater depths at various places in the study area. The entire area's average groundwater depth (feet) was found to be in the range of <4 to >18. A widespread 6 to >18 ft. average groundwater depth was seen in the southwest region of the study area. Though the maximum area of the southwest region had an average groundwater depth of 10–12 ft, higher groundwater depth was observed in some parts. Small clusters of 6–8 ft., 8–10 ft., 12–14 ft., 14–16 ft., 16–18 ft. and >18 ft. were traced in this region.

Table 11 Areal extend of lineament length density

Lineament length density	Area (sq. km)
<1	8378.50
1–2	7835.24
2–3	591.87
3–4	119.03
4–5	64.88
5–6	32.83
6–7	19.69
7–8	16.25
>8	2.41

A larger portion of the southeast region was observed to have 6–8 ft. and 8–10 ft. average groundwater depth. Few parts of this region were detected with 10–12 ft., 12–14 ft. average groundwater depth. A large portion of the northwest region was detected with 8–10 ft. average groundwater depth though some places were spotted with 6–8 ft. and 10–12 ft. average groundwater depth. The average groundwater depth of 10–12 ft. was found over a large portion of the northeast region. Some places were detected with 8–10 ft., 12–14 ft. and 14–16 ft. average groundwater depth. A small amount of average groundwater depth pixels lying in the range of 6–8 ft. was also noticed in this region.

The outputs of the site suitability model for canal outfall and canal routing model (CRM) showed that the models could generate suitable sites and least-cost paths for the proposed canal outfall locations corresponding to the derived gravity canals. Hence, two suitable gravity canal routes were generated by CRM and consequently, two suitable canal outfall locations were found to be useful. The outcomes of the site suitability model for canal outfall and canal routing model (CRM) were validated precisely to check the accuracy of the model performances when verified with each input layer. It was noticed that the site suitability model for canal outfall could generate a coherent and meaningful output raster which was again classified into five classes for further studies. The classified raster outcome of the model included highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable classes (Fig. 5). The useful canal outfall locations were identified to be located in moderately suitable areas (Fig. 9). When verified with the slope raster, the canal outfalls were found to be sited in nearly level to gently sloping terrain (https://www.agry.purdue.edu/soils_judging/review/slope.html) (Table 12). Canal outfall at position 1 was at the slope range of 2–4% and canal outfall at position 2 was at <2% slope (Fig. 4). From this, it can be well understood that locations of the canal outfalls were in the areas having higher surface water detention period, hence facilitating more groundwater recharge. Verifying the canal outfall locations with the LU/LC map, the outfall locations were spotted on the fallow class without any hindrance on cropland, forest area, built-ups, mining and industrial areas and as a benefit the fallow zones were found to be re-used (Fig. 8). The canal outfall

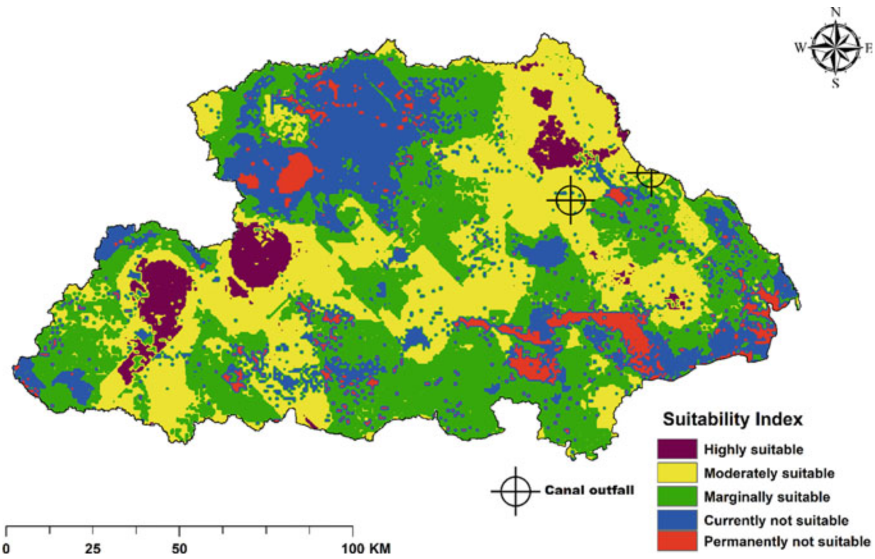

Fig. 5 Site suitability map showing canal outfall locations

Table 12 Slope class, percent and description

Slope (%)	Slope class	Description
0–2	A	Nearly level
3–6	B	Gently sloping
7–12	C	Moderately sloping
13–18	D	Strongly sloping
19–25	E	Moderately steep
26–35	F	Steep
>35	G	Very steep

locations when verified with the lineament length density map, the outfall positions were identified in the lineament length density range of <1 km per sq. km (Fig. 9).

The limitation of lineament length density was previously mentioned and with that understanding, it was clear that the canal outfall positions might not cooperate with the chance of canal failure. Concerning the average groundwater depth, canal outfall positions were traced in the zone of the widespread 10–12 ft. (Fig. 6). It can be perceived that a reasonable demand for groundwater was present in that region. These outfall locations were an essential input in the canal routing model (CRM). From the generated outcomes of CRM, it can be said that the model was able to produce rational and significant results. Two gravity canal routes referring to the least-cost paths were generated by the CRM. The canal routes were further validated with their input layers to check the model's efficiency. While verifying with the slope raster, it was observed that the model was unable to create any route in the southern

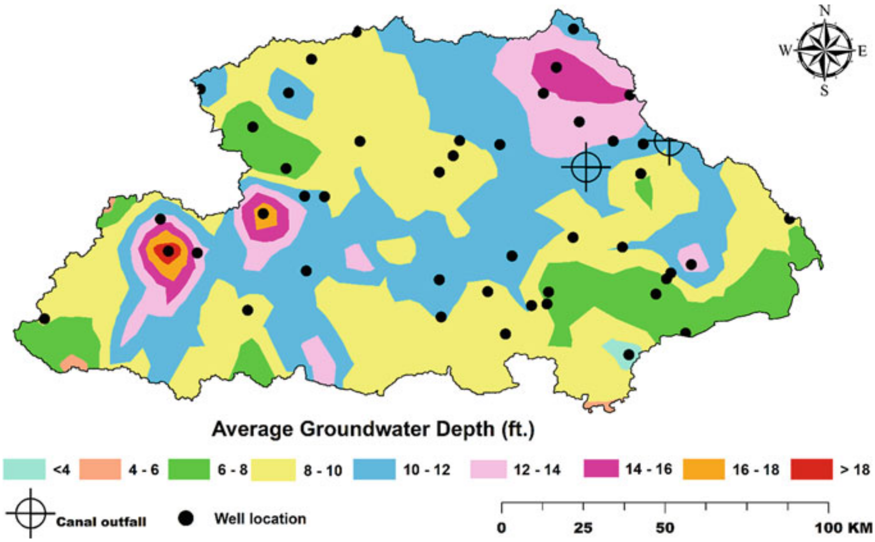

Fig. 6 Average groundwater depth map showing the canal outfall locations

part of the study area because of its topographic condition as the top portion of the southern region is covered by highly undulated terrain.

On the other hand, the northern part of the study area was less undulated; therefore, the model was able to create only two routes, i.e., canal route one and canal route two which were entirely located in the northern part of the study area (Fig. 7a, b). It was noticed that the derived canal routes run along the natural slope of the topography (higher elevation to lower elevation) to meet their respective canal outfall positions. When verified with the LU/LC of the study area, the canal routes did not intersect any water body, built-up, mining or industrial area. The maximum run of the canal routes was found to be in the fallow class though some portion laid in open forest class and successfully met their respective outfall locations (Fig. 8). While verifying the canal routes with the lineament length density map, canal route 1 was observed to run its maximum length in <1 km per sq. km. and canal route 2 was found to run nearly half of its length in <1 km per sq. km to meet their respective outfall locations. The remaining length of both canal routes was noticed to run through a lineament length density of 1–2 km per sq. km (Fig. 9).

4 Conclusion

The study's purpose was mainly focused on diverting the superfluous surface runoff from the places that were flood-prone through gravity canals to the groundwater depleted zones of the study area, proposing a site suitability model for canal outfall

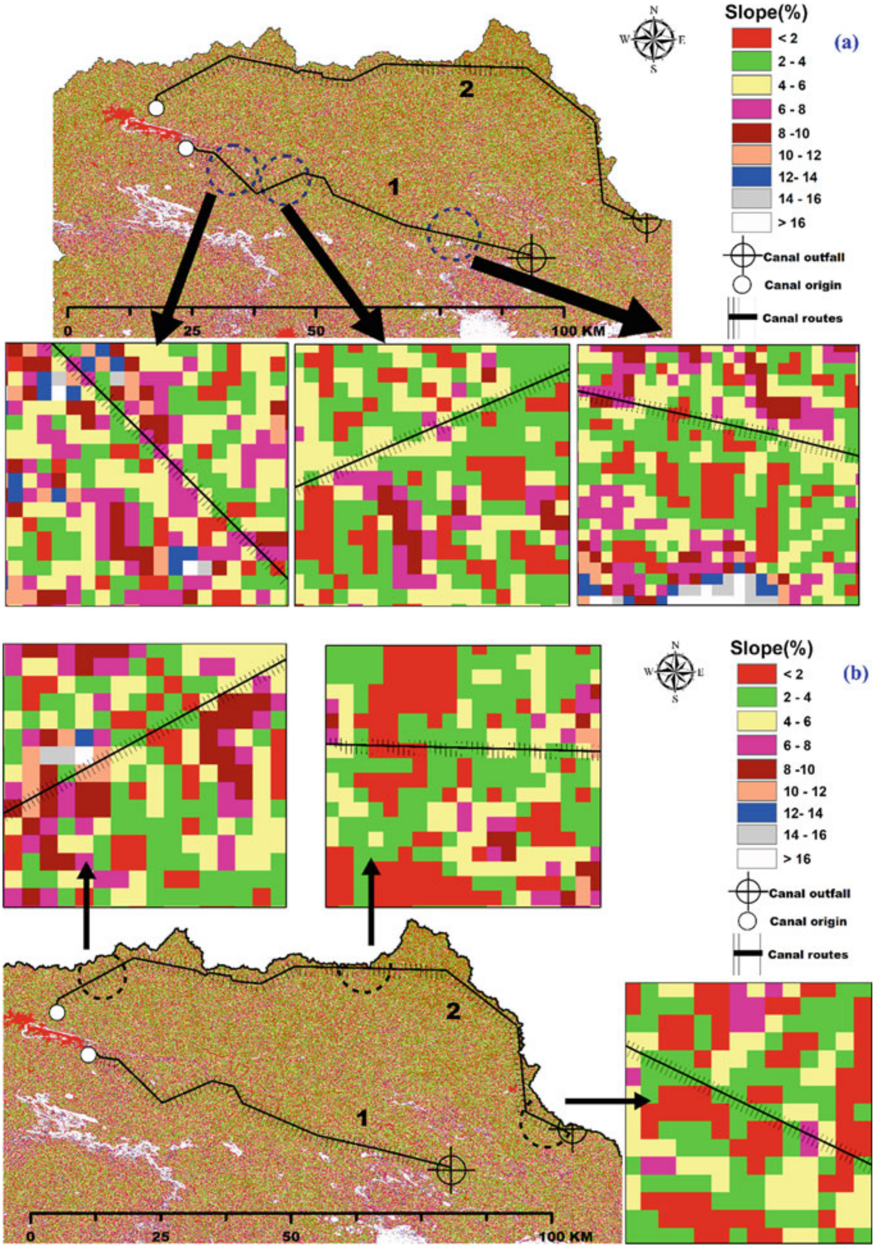

Fig. 7 Slope map showing the least-cost gravity canal routes

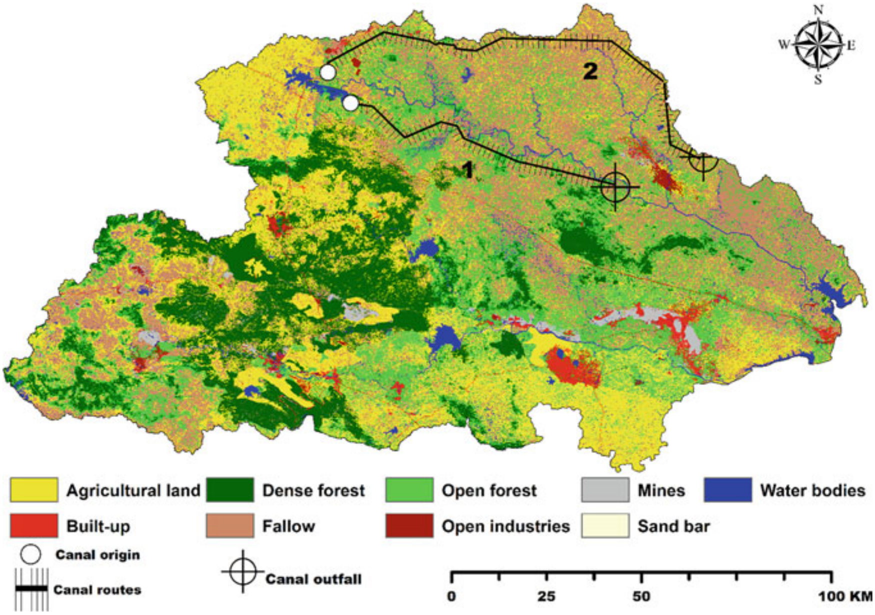

Fig. 8 Land use/land cover map showing the canal outfall locations and gravity canal routes

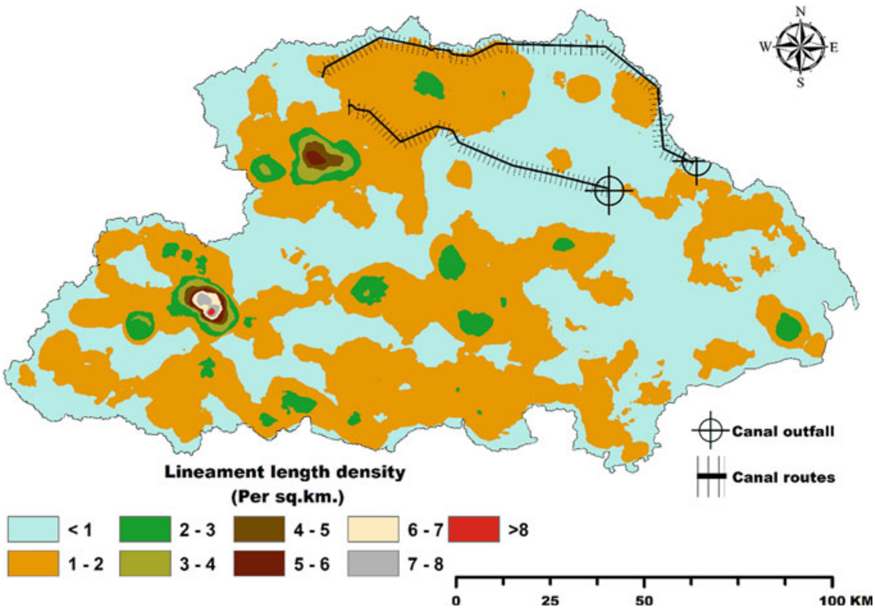

Fig. 9 Lineament length density map showing the canal outfall locations and gravity canal routes

and canal routing model (CRM) exclusively built-in ArcGIS environment. The site suitability model for canal outfall combined factors like DEM, LU/LC, lineament and water table depth of the area of interest, whereas canal routing model (CRM) considered DEM, LU/LC, and lineament for its performance. Both models were able to produce coherent and meaningful results that might be helpful to the planners, decision-makers, and hydrologists for cost-effective routing of surface water. The quality and accuracy of the model outputs were assessed through the validation process followed by precise verification of the end products with their corresponding input layers. ArcGIS was found to act as a potent tool for integrating numerous information and evaluating them to meet the aim of the study. The ArcGIS tools were highly efficient in screening the entire study area with greater accuracy and generating economical canal routes. It might be beneficial to incorporate soil texture data to generate a more accurate site suitability map for canal outfall in future work.

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Assessing the Impact of Disasters and Adaptation Strategies in Sundarban Biosphere Reserve, India: A Household Level Analysis

Mehebub Sahana, Sufia Rehman, Raihan Ahmed, and Haroon Sajjad

Abstract Frequency of climate change-induced multi-hazards has increased, making coastal areas at greater risk. Thus, devising the suitable adaptation strategies is essential for reducing the impact of such hazards on local communities. Most of the earlier studies touched upon different aspects of vulnerability to coastal disasters, community-based adaptation remained under unnoticed in the existing literature. In this paper, an effort has been made to examine the impact of disasters on coastal communities and explore appropriate adaptation strategies in the Sundarban Biosphere Reserve, India. Data related to various aspects of coastal disasters were collected through questionnaire from 570 households in the study area. The findings revealed that cyclone and flood and their associated effect salinity intrusion and coastal erosion have largely affected the coastal communities. Participation of communities, early-warning system, monitoring of flood hazards, establishment of cyclone centers, construction of embankment, adequate healthcare facilities and diversification of livelihood are suggested for future hazards mitigation.

Keywords Disasters · Coastal communities · Early warning systems · Adaptation · Mitigation

M. Sahana
School of Environment, Education and Development (SEED), University of Manchester, Manchester, UK

S. Rehman
Department of Civil Engineering, National Institute of Technology Karnataka, Mangalore, India

R. Ahmed
Department of Geography, Nowgong College, Guwahati, India

H. Sajjad (✉)
Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India
e-mail: haroon.geog@gmail.com

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1 Introduction

Climate change and resultant global human migration are pertinent and imperative challenges these days. Climate change-induced migration stems from disruption of natural disasters and acute changes in the geo-ecological conditions of any region. However, climate change-induced human mobility is quite less understood and received scant attention from researchers (Reuveny 2007). Intergovernmental panel on climate change (IPCC) signified that cyclone and drought are the two main climate extremes leading to human migration globally (IPCC 2007). These two natural events are not related to migration directly but their resultant impacts are seen as losses, outbreak of diseases and poverty. All these consequences push the local communities to migrate ex situ. It is reported that any increase in sea level rise, inadequate water supply and potable drinking water and food insecurity will likely to displace 143 million people from Asia, Sub Saharan Africa and Latin America and render them as climate refugees (World Bank 2018). Sudden strike of natural disasters in East Asia and Pacific region has displaced nearly 7 million people in 2017. Intensive floods in Malaysia have displaced around 15,000 people in January 2018. Bangladesh, India and Pakistan are at highest risk of disasters displacement. In 2017, disasters have displaced around 3 million people in India, Nepal, Bangladesh and Sri Lanka (IDMC 2018). The debate on climate change-induced out-migration has usually been perceived to have arisen from failure of in situ adaptation by an individual or a community. In many cases, out-migration is also caused by the misconception of future climate change impacts. Though various scholars have attempted to assess the nature of climate change-induced migration (Lohrmann 1996; Tacoli 2009; Methmann and Oels 2015), still in-depth analysis is required for documenting suitable strategies for adaptation.

Climate change-induced migration has gained momentum of scientific community. Such migration is directly influenced by the availability of food, health facilities and livelihood opportunities. The main aspect of concern is to address various problems of climate refugees in a totally different socio-political scenario. Biermann and Boas (2010) accentuated that scant concordant in defining climate refugee is the main reason of less scientific attempts. They urged that global governance and recognition of climate refugees will help in uplifting the condition of the climate change-induced displaced population. Holling (1973) pioneered the concept of resilience and categorized it into engineering and ecological resilience. Engineering resilience refers to the extent of disruption to a system and effort to back in equilibrium while ecological resilience or adaptation refers to the ability to perform in a given situation. Equilibrium is less important in case of ecological resilience. Climate change has potential implications on human mobility patterns and consequently climate change-induced migration has emerged as an important adaptation strategy to mitigate from the losses (McLeman and Smit 2006). Migration has evolved as a nobel quintessential adaptation strategy within the climate-related studies and gained attention of savants globally. Bettini (2014) examined that climate-induced migration as an effective adaptation strategy for the agonized people. However, the lack of political interest causes enormous difficulty to the displaced population. Many savants globally examined different adaptation strategies in the prevailing scenario of climate change (Iati 2008; Mwendwa and Giliba 2012; Denkyirah et al. 2017). Sauerborn and Ebi (2012) accented that adaptation strategies can be seamlessly helpful in reducing the impact of extremity of climate events and enhance the further resiliency from floods, droughts, landslides and resultant health implications. Climate change induced severe flood events on mining industry and in situ adaptation strategy in Queensland, Australia was well documented by Sharma and Franks (2013). They advocated that in situ adaptation strategy can reduce the vulnerability to disaster losses and at the same time increases the coping ability of community during the onset of next disaster event. Dhanya and Ramachandran (2016) examined the adaptation strategies adopted by the farming community and their perception on changing climate in semi-arid parts of Southern India. Four important climate parameters as rainfall, temperature, wind and cloud were selected to assess the climate variability in the region. They utilized focused group discussion method to identify the major adaptation strategy and outlined that farmers have adopted specific coping mechanism as per their requirement. Furthermore, effective management of climate-induced out-migration can seamlessly be beneficial in minimizing many conflicts and humanitarian crisis in developing countries. Mapping of coastal disasters is necessary to identify the community and areas exposed to disasters and enables in decision-making for coastal management. De Pippo et al. (2008) examined and mapped the coastal hazard of Northern Campania coastal region, Italy. They analyzed the exposure of each geomorphic unit in the region to various coastal hazards. Batista (2018) prepared coastal flood hazard map for PECUIM Chivirico coastal region to examine the different scenario of the flood. Rani et al. (2018) analyzed the coastal hazard vulnerability in Vizianagaram-Srikakulam coast of Andhra Pradesh using coastal vulnerability index. Geospatial techniques, multicriteria decision-making approach, frequency curves, genetic algorithm, decision trees, support vector machine, ensemble and novel hybrid approach, hydrodynamic model, three-dimensional landscape visualization, Bayesian probabilistic model and generalized linear model, etc., are the advance models and approaches used for disaster vulnerability analysis (Hapke and Plant 2010; Dou et al. 2015a, b, c, d, 2019; Yang 2016; Camilo et al. 2017; Batista 2018; Thai Pham et al. 2018; Nelson and Burnside 2019).

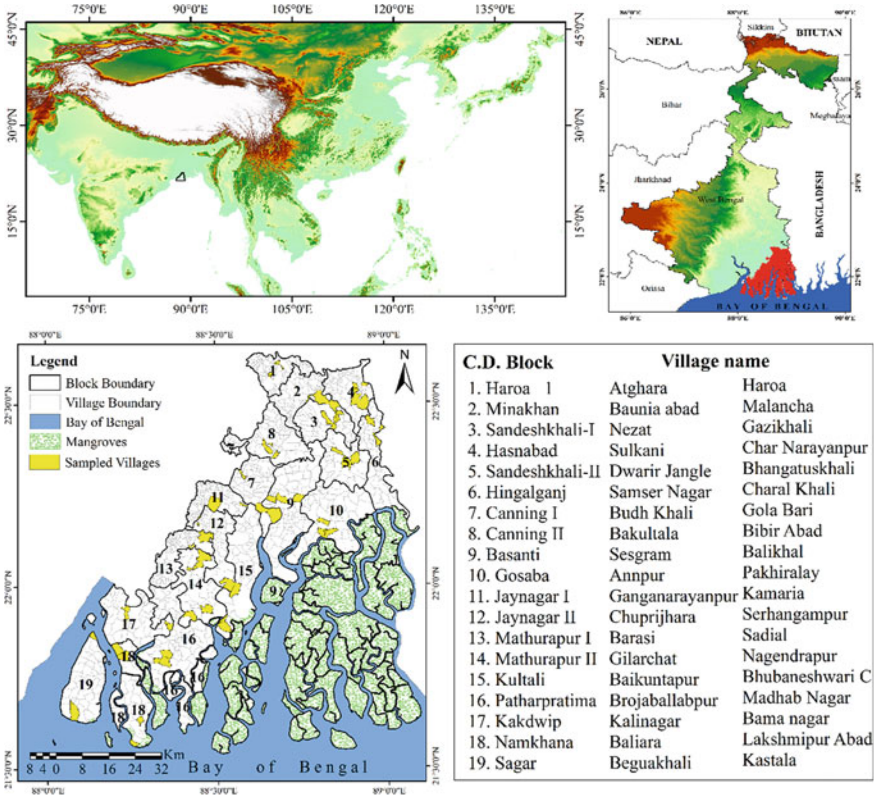
Interaction among exposure, hazard and vulnerability increases the risk and susceptibility to climate change. Transformation in the biological, chemical and physical properties of the environment can lead to changes in sea level rise, temperature & rainfall, ocean currents and wave action (Kassem et al. 2019). Climate change impelled sea level rise in Asian countries has severely affected the coastal communities and livelihood (Oo et al. 2018). Thus, adaptation strategies in the climate change scenario especially in the fragile deltaic ecosystems are prerequisite to safeguard the coastal communities. The nature of adaptation has also been found changing according to the implications of the location and human potentials (Evers and Pathirana 2018). Matemilola et al. (2019) analyzed the implications of climate change in the Niger Delta Region. They emphasized that efficacious policy measures are required to reduce the impact of climate change on food security, water resources and ecosystem functionality. Bloemen et al. (2018) analyzed the policy implications of climate change and suggested coping strategies in deltaic Dutch ecosystem. They concluded that theoretical and practical lessons can go for a long way in dealing with the effects of climate change. Tashmin et al. (2018) identified constant onset of disaster, poverty, illiteracy and population density as the prime drivers of increasing vulnerability in coastal Bangladesh. They asserted that the indigenous knowledge and understanding of the disasters are effective in taking adaptative measures for lessening vulnerability (Tashmin et al. 2018). Roberts et al. (2017) analyzed the role of marine reserves in formulating adaptation strategies to climate change. Creation of marine protected areas, increasing reproductivity of species by establishing the regional linkages between biosphere and low impact fishing methods are some of the important adaptative measures for enhancing the coping capacity of the coastal Reserves. Prudent health facilities, improvement in agriculture and fisheries, better livelihood opportunities can reduce the poverty and overall coastal vulnerability in Caribbean Island (Mycoo 2018). Provision of safe drinking water, scrupulous water availability for irrigation and increase in the education and awareness among local communities can uplift the adaptive capability of the coastal communities residing in the Reserve (Rabbani et al. 2018).

Migration is usually less a function of the immediate decision taken aftermath of any natural disaster, rather it is decided before the occurrence of any such events (Boano et al. 2008). For example, along coastal Bangladesh, about 20 million inhabitants have internationally migrated too many parts of the world due to frequent multi-hazard events and landlessness (Siddiqui 2005). It is also found that more than 100,000 people were left homeless, hundreds of rivers embankments were breached and nearly 50,000 ha of agricultural land were lost aftermath Aila cyclone. Sundarban deltaic coast, which stretches across the mouths of the Ganges, in both India and Bangladesh, is subjected to climate change and resultant numerous hazard events (Chittibabu 1999). Its geographical location and topographical characteristics particularly make it vulnerable. Fragility and ecological dynamism mark the two distinct characteristics of Indian Sundarban. Storm surge flood has emerged a great challenge to the communities of coastal areas in Sundarban (Sahana and Sajjad 2019).

Majority of the rural population is under the constant exposure to natural disasters. Implications grow with less adoption of mitigating strategies as no livelihood opportunities are available. Idealizing all the facets, this study is a modest attempt to find out the effective and preferable adaptation strategies adopted by local communities in SBR. A brief elucidation of the ex situ adaptation (migration) and in situ adaptation strategies adopted by various social groups in the SBR were also outlined here. No nascent efforts have been made to assess coping mechanism for suitable adaptation by the individual community in the Reserve. Fragility and dynamism of this deltaic ecosystem have necessitated to formulate the suitable adaptation strategies to climate change. This study also intends to minimize the gaps in studies on adaptation strategies solely focusing on single hazard. This study embryonically examined the socio-economic status of respondents, income disparity and implication of disasters in the Reserve. A close disclosure of respondents' experience and impact of climate change on their livelihood sources were also credibly enunciated. Contrasts between the in situ and ex situ adaptation strategies were analyzed using multinomial logistic regression (MNLR) model. In situ and ex situ adaptation strategy preferences by local communities will ameliorate the understanding of conservationist and environmentalist to formulate momentous management strategies in the Reserve.

2 Study Area

Indian Sundarban Reserve stretches across 21°31′ N and 22°30′ N latitudes and 88°10′ E and 89°51′ E longitudes (Fig. 1), comprising of 1063 villages spreading over 19 community development blocks (administrative subdivision of the district) and is inhabited by 4.37 million people (Census 2011). It consists of a total of 102 large and small islands, of which 48 are uninhabited and 54 are inhabited. Tropical cyclones and floods are regular extreme weather phenomena in the study area during



C.D. Block	Village name	
1. Haroa I	Atghara	Haroa
2. Minakhan	Baunia abad	Malancha
3. Sandeshkhali-I	Nezat	Gazikhali
4. Hasnabad	Sulkani	Char Narayanpur
5. Sandeshkhali-II	Dwarir Jangle	Bhangatuskhali
6. Hingalganj	Samser Nagar	Charal Khali
7. Canning I	Budh Khali	Gola Bari
8. Canning II	Bakultala	Bibir Abad
9. Basanti	Sesgram	Balikhal
10. Gosaba	Annpur	Pakhiralay
11. Jaynagar I	Ganganarayanpur	Kamaria
12. Jaynagar II	Chuprijhara	Serhangampur
13. Mathurapur I	Barasi	Sadial
14. Mathurapur II	Gilarchat	Nagendrapur
15. Kultali	Baikuntapur	Bhubaneshwari C
16. Patharpratima	Brojaballabpur	Madhab Nagar
17. Kakdwip	Kalinagar	Bama nagar
18. Namkhana	Baliara	Lakshmipur Abad
19. Sagar	Beguakhali	Kastala

Fig. 1 Location of the sampled villages in SBR

pre-monsoon period. Embankments protect the low-lying islands against the action of storm surge and coastal flooding events. This Reserve is marked by a dense network of tidal water which raises its vulnerability to storm surge. Average tidal amplitude ranging between 4 and 5 m occurs during July–August (Sahana and Sajjad 2019). Creeks, channels, mud and salt flats, mangrove swamps, beaches, estuary and alluvial plains are the distinct geomorphic features in the SBR (Ganguly et al. 2006). Dynamic interactions of currents (littoral), tides and waves in combination with other fluvial components led to the formation of these geomorphic features. Mangrove forest itself provides buffer against storm surges, coastal instability, pollution and attaining enormous resources to the dependent population. The deltaic region is divided into three aquifers zones. The first two zones are saline in nature dividing the fresh aquifer by a thick clayey layer. Dense network of tidal creeks and channels makes this region susceptible to floods, storm surges and cyclones. These disasters often led to high coastal erosion and damages to infrastructure (Danda et al. 2011). SBR with unique geomorphic setting has been affected by various storm surge events namely Akash (May 2007), Sidr (November 2007), Aila (May 2009) and Mahasen (May 2013). SBR has also a long history of flooding from last several decades (Dhara and Paul 2016). The study area has far reaching implications of climate change. This Reserve is extremely susceptible to climate change-induced coastal hazards, sudden onset of storm surge, cyclones and floods. Agriculture and fishing are the major economic activities of the rural communities in the study area. Remoteness, poverty and inequality of resources are the big challenges. Of the total population, nearly 43% population live below the poverty line. Loss of agricultural land as a result coastal inundation, inadequate amenities and facilities are the chief characteristics of most of the islands in SBR. In this backdrop, the efficacious adaptation strategy will be helpful in reducing vulnerability and smack of extreme weather events.

3 Database and Methodology

A total of 570 households were sampled purposively from the study area for assessing credibly the effects of natural hazards on the local communities and identifying the suitable adaptation strategies devised at the household level. Two villages (one adjacent to the coastline or riverbank and one farther inland) were selected randomly from each block (the study area has been divided into 19 blocks). In this way, 38 villages were selected randomly from the study area (Fig. 1). From each of the village high, medium and low-income category households were chosen and enumerated in the ratio of 1:10. The respondents were asked to disclose the most suitable adaptation strategies on a five-point scale.

Lorenz curve and Gini coefficients were used to estimate the per capita income inequality for surveyed households. The wealth index (monetary and physical assets) was estimated by using the PCA composite index. The Gini coefficient was calculated as:

$$\text{GiniCoefficient} = \frac{A}{A + B} \tag{1}$$

$$\text{Ginicofficient} = 1 - \sum_{i=1}^{n} (X_{i-1} - X_i)(Y_{i-1} + Y_i) \tag{2}$$

where, X refers to cumulative share of population, and Y represents the cumulative share of wealth. In the Gini coefficient '0' indicates absolute equality and 1 indicates maximum inequality.

Multinomial logistic regression (MNLR) model (Greene 2003) was used to identify the most preferable adaptation strategies in the SBR. The model was also used to examine the association between the explanatory variables and the most preferable adaptation strategies. For estimation of the MNLR model, first dependent variable and the last independent variable were selected as reference variable. In the MNLR, the ratio of each pair of class $\left(Y_{j,} Y_1\right)$ can be calculated as:

$$\log \frac{(Y = j|x)}{(Y = 1|x)} = \alpha_j + \beta_j x, \tag{3}$$

where x is the vector containing the predictor variables, a_j the intercept parameter for the jth level and b is the vector of regression coefficient. The probability of a household employing a strategy j can be computed on the basis of its features contained in the vector x the equation:

$$P(Y = j|x) = \frac{exp\left(\alpha_j + \beta_j x\right)}{1 + \sum_{h=2}^{j} exp\left(\alpha_h + \beta_j x\right)} \tag{4}$$

where $j = 1$ is baseline category, a_1 and $b_1 = 0$. Thus, when looking for the probability of an adaptation strategy belonging to the baseline level, it is easy to compute the numerator, since exp (0) = 1. The value of the denominator is the same for each 'j'. Estimation of the parameter provides only the direction of the effect of the independent variables on the dependent variable, but the estimates do not represent either the actual magnitude of change nor probabilities. Multinomial logistic regression (MNLR) model is an important statistical tool in categorial analysis and predicts the explanatory variables. This model constructively analyzes the variables having more than two categories and simultaneously provides a comparison among them (El-Habil 2012). MNLR is also a powerful tool as it does not make any assumptions of linearity, normality and homoscedasticity. MNLR has an advantage over other models as it takes into account due consideration for making decisions (Starkweather and Moske 2011).

4 Deliberation of Results

The summary of statistics of the sampled households is presented in Table 2. Most of the respondents in the sampled households were males (80.4%). The average age of the respondents was 44.75 years. Only those respondents were interviewed whose age was more than 21 years. The average family size was 4.75. The average income of the sampled households was Rs. 5467 (1$ = 71.12 Indian rupees). Nearly 39% households were below poverty line. Wide income inequalities existed among the sampled households (Gini coefficient 0.297). Nearly 31% households belong to farmers' category. Most of the sampled households (63%) were not having toilet facility and another 32% households were deprived of electricity connection in the study area. The Lorenz curve shows that about 20% sampled households earned 40% of the total income and about 20% sampled household's shared 55% wealth of the total households (Fig. 2). Most of the sampled households (69%) did not own any agricultural land (Table 2). Most of the sampled households were not connected with the paved road.

About 12.5% households used pond/river water for drinking purposes. More than half of the sampled households fetch water from 500 m distance. Nearly 20% sampled households fetch water from a distance of more than 1 km while 12% sampled households walk up to 1 km to fetch water. Of the sampled population about 67% persons were workers (15–59 years) followed by 15.5% teenagers (7–14 years), 10% children (0–6 years) and 7% elderly people (59 + years). Most of the respondents of the sampled households were illiterate (37.9%). Majority of the respondents live in the muddy houses (64%). Most of the sampled households belonged to lowest ladder of the society. Nearly 70% of the respondents possessed their own house. About 14% respondents had built their house on *Khas* land (government provided land) while only 8% respondents live along rivers and road side. The main occupation of the

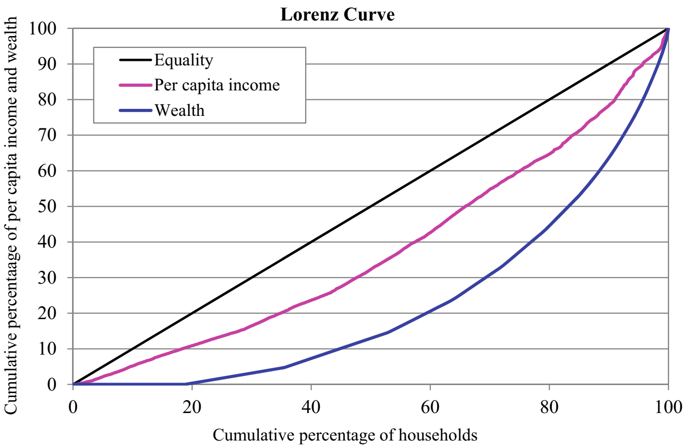


Fig. 2 Per capita income and wealth inequality among sampled households in SBR

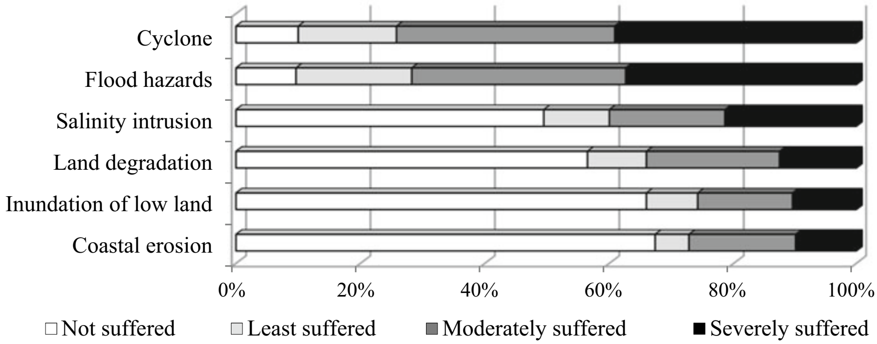


Fig. 3 Households' response to suffering from various natural hazards events

respondents was agriculture (18%) followed by daily wage laborers (17%), fishing (12%), seasonal migrants (12%), petty businessmen (3%) and government servants (2%). Most of the respondents of the sampled households had lived in SBR since their birth. Nearly 14% respondents were migrants from other areas in the Reserve.

4.1 Effect of Hazards on Livelihood

The degree of households' suffering from hazards and their effects on their livelihood sources were measured for floods, cyclones, salinity intrusion, land degradation, inundation of lowland and coastal erosion. Most of the sampled households suffered severely from cyclones (39%) followed by flood (37%) and salinity intrusion (21%). Land degradation moderately affected the sampled households (Fig. 3). Inundation of low land and coastal erosion hazards affected the sampled households least in the study area.

The households were also asked to disclose their experience about the impact of climate change on their livelihood sources (Plate 1). Nearly 34% households reported that their fish production/catch had severely suffered. Another 19% respondents reported decrease in their crop production. About 23% households disclosed their livestock population has decreased while only 9% households were of the opinion that honey production has decreased (Fig. 4).

The degree of suffering from natural hazards varied in different administrative blocks of SBR. Most of the sampled households of Sagar, Gosaba, Namkhana and Patharpratima were severely affected while households in Hingalganj, Kultali, Kakdwip, Basanti blokes were moderately affected blocks from all the selected natural hazards. Sandeshkhali-I, Sandeshkhali-II, Minakhan and Hasnabad were the least affected blocks. The households that were positioned in the middle part of the reserve have suffered the least. Most of the sampled households in Haroa, Canning I,

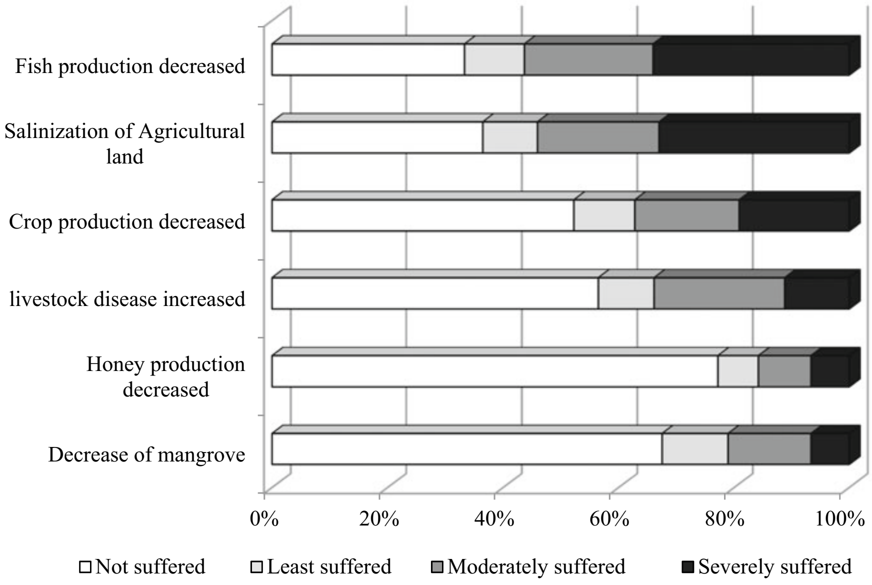


Fig. 4 Households' response to suffering from decrease in livelihood sources

Fig. 5 **a** Settlements vulnerable to river bank erosion along the *Matla River* bank in Basanti block; **b** Settlement vulnerable to coastal erosion at Baliara village of Namkhana block, this village is just 200 m away from the coast, **c** A bamboo bridge in a broken embankment; **d** River bank failure and intrusion of salt water in agricultural land in Gosaba block. *Source* The field photographs taken by the authors during December, 2017

Canning II, Jaynagar I, Jaynagar II, Mathurapur I, Mathurapur II blocks have usually not suffered from the selected natural hazards (Fig. 5).

Flood, salinity intrusion, cyclone, sea-level rise and erosion were identified as the most recurring natural hazards, which affected severely the economic activities of the rural households in the study area (Fig. 6). Our finding is in accordance with Danda et al. (2011). They have also identified coastal areas at greater risk of disasters experiencing inevitable losses, damages to infrastructure and decrease in livelihood. Agriculture and livestock activities were mostly affected by floods. The maximum effect of salinity intrusion was found on shrimp culture and fishing. Honey production and gathering was mostly affected by the severe cyclones. Due to salinity intrusion, many agricultural lands in SBR have turned fallow land and which sometime devoted to fishing or shrimp culture activities. Regular occurrence

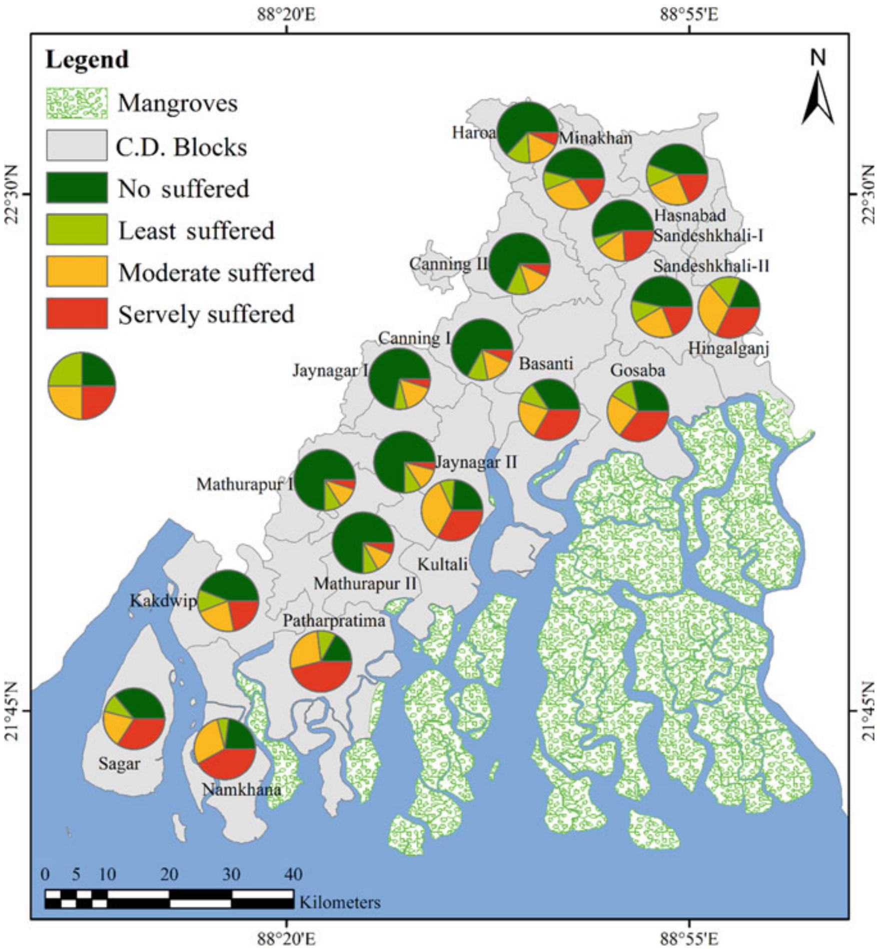


Fig. 6 Spatial variation in climate suffering in different blocks of SBR

of flood hazards, cyclones and salinity intrusion have affected the entire economic system and forced people to migrate from the SBR. A case study by Mahadevia and Vikas (2012) also revealed that apart from disasters, climate change has severely impacted the agricultural patterns, growth of mangrove species and affected overall ecological environment of the Reserve.

The preferred adaptation strategies for the households were listed as alternative crops, cultivating high yielding varieties of rice (HYV), alternative fish varieties, prawn cultivation, poultry and duck rearing, reclaim the degraded land, cultivating vegetables, migration, off-farm work (van, rickshaw, driving) and petty business, and on the basis of their respective choices, these were rated as; not effective, somewhat effective, moderately effective, highly effective and very highly effective. Results revealed that the most effective and preferred adaptation strategy was out-migration from the SBR. More than 60% of the respondents felt that migration was highly to very highly effective adaptation strategy for coping with the recurring natural hazards and climate change effects within the SBR (Fig. 7). Those who were not able to adjust to the changing environmental and socio-economic conditions basically tried to move out from the region and most of such respondents belonged to younger age group. Thus, out-migration is the ex-situ adaptation strategy and its preference has risen further after the cyclone Aila in 2009 while prawn cultivation and alternative fishing activities were preferable and effective in situ adaptation strategies. Growing alternative crops, reclaiming degraded lands and cultivating HYV rice varieties were perceived as moderately effective adaptation strategies. These strategies were adopted by the respondents living away from the coastline. Cultivation of vegetables, poultry and duck rearing were somewhat effective adaptation strategies

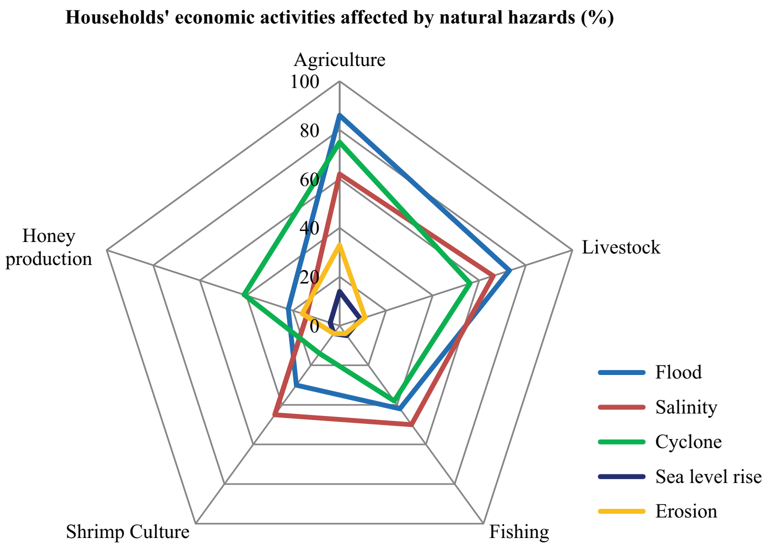


Fig. 7 Extent of natural hazards afflicting respective economic activities in SBR

since most people regarded these as being beneficial to their livelihood strategies. Finally, off-farm work and petty businesses were not the most effective adaptation strategies in the study area and 66 and 51% respondents did not prefer petty business and off-farm work as being viable alternatives. The respondents living in remote and vulnerable islands preferred ex-situ adaptation strategies while the respondents living in significantly salinity affected and coastal blocks with good transport linkages to the state capital Kolkata preferred intensified in situ adaptation strategies such as alternative fish varieties and prawn cultivation. Ghosh et al. (2018) identified that lack of knowledge and awareness among communities are creating barriers for taking effectual adaptative measures. The communities living along the embankments also reaffirmed that if their overall social and economic conditions got better, they will move to the safer villages. Furthermore, proper installation of early warning system, awareness and knowledge generation about disasters, mudflat restoration, establishing community aquaculture, rejuvenation of mangrove species and climate risk awareness program can also be adopted to reduce the vulnerability of coastal Islands (Danda 2010; Ghosh et al. 2018).

A multinomial logistic regression was run to understand the association between explanatory variables and the most preferable adaptation strategies such as migration, alternative fish varieties and prawn cultivation, alternative crops and cultivating HYV rice varieties and others (Table 1).

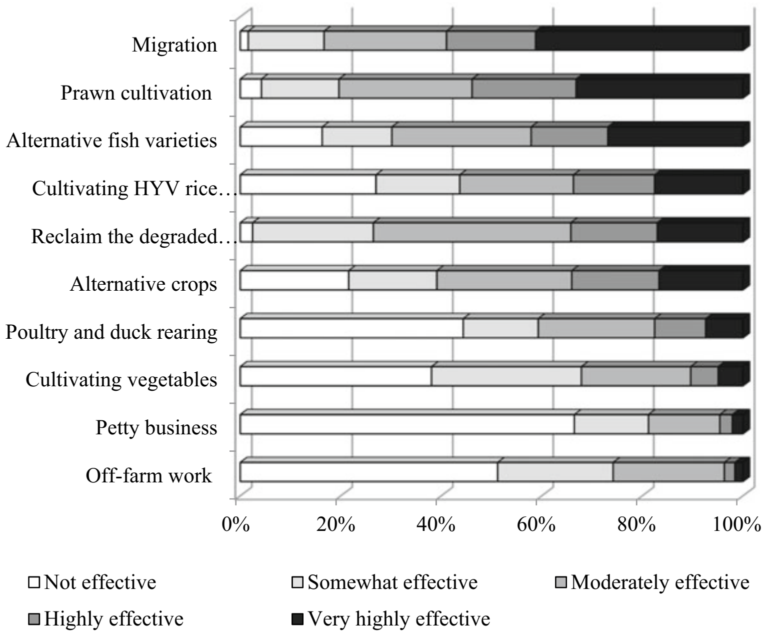


Fig. 8 Effective adaptation strategies opted by the Sundarban community

Table 1 Multinomial logistic regression analysis between the adaptation strategy and explanatory variables of the sampled households in SBR

Explanatory variables	Migration	Alternative fish varieties and prawn cultivation	Alternative crops and cultivating HYV rice varieties
Social group (General*)			
OBC	0.5526 (0.2709)	1.4869 (0.6509)	0.4410 (0.2132)
Scheduled caste	1.1184 (0.4509)	1.2530 (0.5005)	0.9270 (0.3727)
Scheduled tribe	65,356.7 (3457.6)***	63,579.5 (3375.6)***	(8991.8)***
Property (Own*)			
Khas (govt. provided land)	0.4316 (0.2029)*	0.6111 (0.2899)	0.4859 (0.2391)
Road/river side	1.4325 (0.5357)*	1.2801 (0.4690)	1.2324 (0.4711)
Land tenure (Cultivator*)			
Lease-in	6.3071 (7.2226)*	0.8266 (0.8042)	1.7720 (2.0994)
Land less farmer	8.9307 (13.315)*	1.7357 (2.3803)	2.1386 (3.3394)
Others (Non-agricultural)	2.9000 (4.8001)***	1.1671 (1.8501)***	2.9877 (4.3919)
Household head age (<30*)			
30–45 yrs	0.3804 (0.1852)**	0.7455 (0.3738)	0.5955 (0.2957)
above 45 yrs	0.4163 (0.2323)	1.3453 (0.7451)	0.9311 (0.5304)
Household size (<3)			
3 to 5	0.9638 (0.4629)	2.1243 (1.0296)	2.0542 (1.0108)
>5	1.0474 (0.5599)	2.5368 (1.3149)**	2.0146 (1.1263)
Education (Illiterate*)			
Primary	0.9567 (0.4201)	0.8418 (0.3602)	0.8927 (0.3994)
Secondary	1.8732 (1.0782)	2.0045 (1.1318)	1.1388 (0.7343)
Graduation and above	0.9382 (0.5065)	0.9634 (0.4696)	0.9425 (0.5072)
Occupation (Farmer*)			
Laborer	0.9282 (0.4336)	1.043 (0.47953)	0.8769 (0.4209)
Fishing	0.3059 (0.1618)**	0.5430 (0.2677)	0.3535 (0.1895)**
Other	0.6959 (0.3157)	0.6412 (0.2919)	0.9391 (0.4279)
Per capita income (<1000*)			
1001 to 2000	1.1722 (0.4496)	1.3755 (0.50339)	1.7275 (0.6631)
>2000	4.2813 (2.9628)**	2.9929 (2.0462)***	1.5714 (1.3059)*

<0.01 = ***, <0.05 = **, <0.1 = * Parentheses show standard error
* is the reference category from the first and the last explanatory variables

The multinomial analysis revealed that people from the scheduled caste social category were most likely to opt for different adaptation strategies in the study area as compared to members from other social groups. The respondents living in *Khas* land or those residing along roads or rivers and young age group (30–45 years) preferred out-migration as adaptation strategy. Migration, alternative fish varieties and prawn cultivation were significantly associated with the respondents engaged in non-agricultural activities in SBR. The respondents having large family size were significantly associated with fishing and prawn cultivation-based adaptation strategies.

Migration and alternative crops and cultivating HYV rice varieties were significant among fishermen. Households with higher per capita income were significantly associated with in situ adaptation strategies. The analysis revealed that preferable adaptation strategies of the households in SBR were highly associated with land tenure, property and household income. The in situ adaptation totally depends on the type of land tenure and property owned. Assets to a greater extent determine the ex situ and in situ adaptation strategies. The respondents having less assets are associated with out-migration adaptations while those with more assets preferred alternative in situ adaptation strategies. Findings of the study would be practical for future hazard mitigation. Cyclone, flood, salinity intrusion and coastal erosion have unprecedentedly affected the communities. Therefore, early warning system, establishment of cyclone shelters, construction of embankments, monitoring of flood hazard, adequate medical facilities, alternative livelihood sources are suggested for future hazard mitigation. Meanwhile balancing the functioning of ecosystem and productivity of mangroves will maintain the long-term sustainability of SBR. Adaptation strategies revealed in the study, if implemented would be useful to cope up with the future hazards.

5 Conclusion and Policy Implication

This study has analyzed the various adaptation strategies adopted by the rural communities in Indian Sundarban Biosphere Reserve. Findings indicated that flood, salinity intrusion, cyclone, sea-level rise and erosion are most frequent phenomena in the study area. Climate change and natural disasters in the Reserve have significantly decreased the fish production, crop yield, mangrove cover, livestock, honey production, salinization of agricultural land and increased erosion along coastal areas. Honey cultivators were also highly affected by frequent cyclonic events. Economic condition of the study area was badly influenced by the constant exposure to floods and cyclones and salinity intrusion. Sagar, Gosaba, Namkhana and Patharpratima were the highest vulnerable blocks in the Reserve and accords priority to habituate suitable adaptation strategy. Results revealed that ex situ out-migration was the most preferable adaptation strategy in SBR. More than half of the sampled household opted to migrate during extreme weather events. Prawn cultivation and alternative fish activities were preferable in situ adaptation strategies. Respondents who live in the coastal island preferred to migrate during cyclonic events. MNLR model analysis revealed that land tenure, property and households' income governed the adoption of coping strategies. Type of land tenure and property owned by the respondents determined the in situ adaptation. The respondents who were engaged in non-agricultural activities preferred out-migration. Adaptation and mitigation can help to increase the coping capacity of the local communities to face and minimize the consequences of the disaster losses. SBR being the most diverse ecological system and home of a large number of rural populations demands constructive mitigation strategies for reducing the extent of vulnerability. At the same time, adaptation will also enhance the capability to cope up with the impacts of climate change. Conventional means, for example, retention ponds will be utilized for collecting the flood water and will reduce the soil erosion along coastal banks. Effectual transport connectivity between coastal island and inland areas will help people to move safely during severe cyclonic events. Preserving the rights of climate refugees is immensely important to lessen the further crises. Saline soils can be brought under cultivation by growing salt-tolerant crops varieties. Government aid during disasters events will benefit the vulnerable community and to bear the losses. Integration of local mitigation strategies, virtuous understanding of stakeholders on climate change and government-provided resiliency will be propitious to decrease the vulnerability in the Reserve. The methodology adopted in the study can be utilized effectively for assessing adaptation strategies in other coastal areas at various scales.

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Forest Fires in Tropical Deciduous Forests—A Precursor to Anticipatory Adaptation Framework

Jayshree Das and P. K. Joshi

Abstract Tropical deciduous forests provide habitat to a wide range of life forms and ecosystem services to mankind. Forest fires in these forests have become an environmental threat that challenges the vulnerability of ecosystems and communities in the immediate vicinity. These also contest the adaptation and resilience as they act as carbon sinks. However, at times forest fires in these Tropical deciduous forests become disastrous and such disasters are expected to increase with the predicted climate change scenarios. These uncontrolled fires often bring damage to the resources and services being provided by the forests. To curb the variety of damages due to fire, the implementation of fire management strategies and the identification of responsible factors is important for disaster risk reduction. Fire susceptibility mapping and modeling of the area provides a framework for the anticipatory adaptation and solution toward reducing the impact of forest fire disasters. The framework for susceptibility mapping guides monitoring and assessment of species richness, soil and vegetation interaction, and changes in the usage of non-timber forest products by the local communities. Though the distribution of fire susceptibility is highly dependent on the terrain conditions, the accessibility to the forest products is determined by their availability. This paradigm shift of forest dominant landscapes from the fire risk zones to community interactive landscapes would enhance the adaptation frameworks for the less studied disasters and their dynamics in the climate change scenarios.

Keywords Forest fire · Susceptibility mapping · Modeling · Adaptation

J. Das (✉) · P. K. Joshi
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
e-mail: dasjayshree145@gmail.com

P. K. Joshi
Special Centre for Disaster Research, Jawaharlal Nehru University, New Delhi, India

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1 Introduction

According to United Nations, wildfire or forest fire can be described as "any uncontrolled and non-prescribed combustion or burning of plants in a natural setting such as a forest, grassland, bushland or tundra, which consumes the natural fuels and spreads based on environmental conditions (e.g., wind, topography)". The widespread distribution of fire contributed to the formation of biomes since 400–350 million years ago approximately (Chowdhury and Hassan 2015; Qadir et al. 2021). Fire plays an ecological dynamism in defining biological structure and function, influencing ecosystem, community, and biome (Bui et al. 2017; Mclauchlan et al. 2020). Recurrent fire events have direct positive and negative consequences on the ecosystem which impact biotic components (Chowdhury and Hassan 2015; Nami et al. 2018).

Recent fire events observed globally are due to two primary reasons, the first as a management tool (also known as prescribed fire) (Mclauchlan et al. 2020), and secondly human actions and climatic shifts are moving fire incidences and the frequency is increasing tremendously (Fox et al. 2016). While the former is avoided by forest managers due to ecological consequences (Mclauchlan et al. 2020), later led to snowballing forest fire incidences and large-scale destruction of biological organisms (Eskandari and Miesel 2017; Mclauchlan et al. 2020). Growing human settlement and developmental society has increased the demand for forest products which intensifies these events (de Belém Costa Freitas et al. 2017). Forest fire cascade carbon cycle which provokes climate change and increases the risk for forest ecosystem with increased biomass accumulation, drought condition, and rising temperature (Feurdean et al. 2017; Briones-Herrera et al. 2019). This builds up the need of predicting future forest fire incidences and understand the priorities of ecological factors to maintain the integrity of multi-functional forests.

Alarming fire events in recent days press the need to understand fire behavior with altering climatic variables and human action (Bui et al. 2017; Eskandari and Chuvieco 2015). In this chapter we present a perspective, on how various ecological components regulate forest fire and vice-versa; the importance of modeling toward prediction of future forest fire—an adaptation strategy, to assist in forest management, early warning system, and resource allocation. We present how the coupling of spatial and temporal satellite remote sensing data for factors, and modeling approaches help to understand the site-specific risk of a forest fire. Our overall perspective is understanding the increased intensity of forest fires, the contribution of biota, biophysical and human action toward the recurrent fire, and predicting increased risk of fire frequency, intensity, regimes, and susceptibility. We would also confer a better modeling approach through comparison study between statistical or weighted modeling and machine learning approach (Fig. 1).

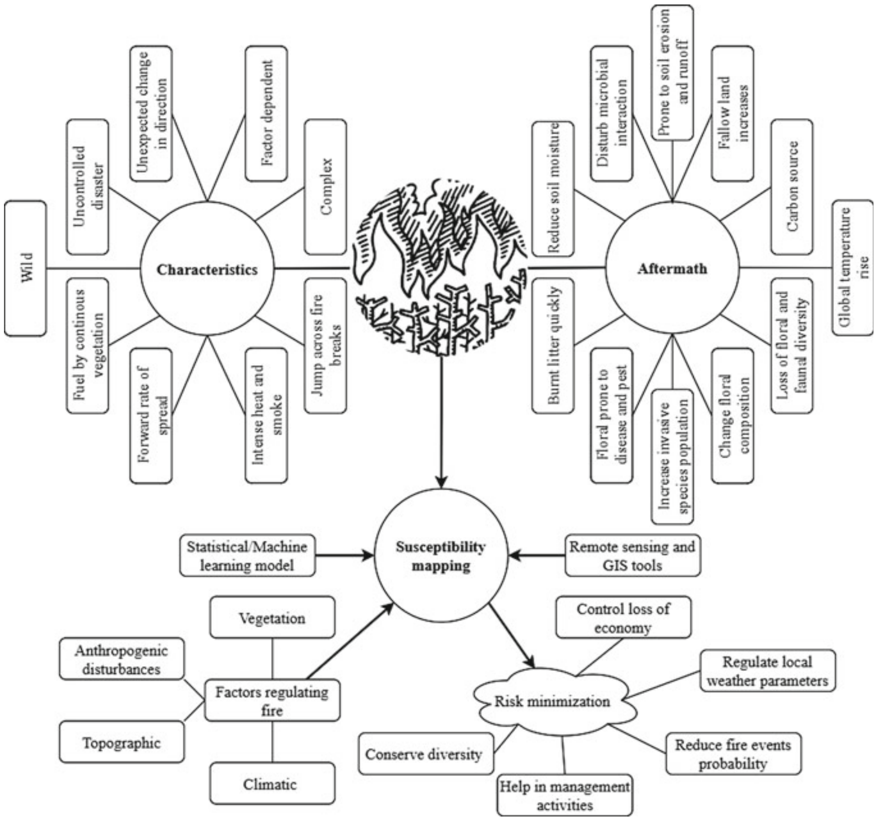

Fig. 1 Forest fire characterization and step to curb the consequences of fire

2 Characterizing Forest Fire Factors

Forest fire is a complex phenomenon that can be well explained from the conceptual model of the "fire regime triangle" (Davis et al. 2017). Nevertheless, fire frequency and intensity are dependent on some fundamental units—fuel supply by predominant forest structure, prevailing topography, climatic condition, and igniting agent (Eskandari and Miesel 2017; Feurdean et al. 2017; Chitale and Behera 2019)—which varies according to spatial and temporal scales. These units are identified as crucial factors to regulate fire actions across the globe.

2.1 Vegetation Composition

Recurrent forest fire events are considered to be the driving force behind the existing structure and composition of biotic communities in terrestrial ecosystems (Mclauchlan et al. 2020). From historical lineages, fire is considered a vital force in the natural selection of biotic communities and other organisms in an ecosystem, landscape, or biome. Studies describe plants have fire-adaptive traits in the evolutionary process like post-fire recruitment, re-sprouting, and fire-resistant or fire promoting (Feurdean et al. 2017; Mclauchlan et al. 2020), which can be recognized from a detailed analysis of phylogeny. Large forest fires occur due to the availability of fuel load produced by existing forest types which is the result of afforestation program, lack of management practices, and migration (Duarte and Teododo 2016; Alcasena Urdíroz et al. 2018; Briones-Herrera et al. 2019). Fuel load management strategy reduces forest fire incidences in vegetation due to fire suppression activities leading to a larger fire in extreme climatic conditions (Fox et al. 2016). A study conducted to understand fuel characteristics in different fire ecosystems shows that tropical forests with heavy fuel loaded moisture restrict ignition more than limited fuel with dry spells (Briones-Herrera et al. 2019). Fuel moisture affects fire as it increases ignition delay time and decreases flame emissivity (Duarte and Teododo 2016).

In tropical forests, fire events can be limited by higher precipitation and fuel moisture (Briones-Herrera et al. 2019). However biotic diversity also affects fire characteristics, broad-leaved deciduous forests have high leaf moisture contributing to a moister microclimate and lower content of flammable volatile compounds, which reduce fire incidences compared to the boreal forest (Feurdean et al. 2017). Fuel dryness connecting active forest increases risk by including multi-variants effects of climate, anthropogenic slash, and burn activity. Understanding the relationship between vegetation structure and composition fuel load production with fire across the globe and future prediction modeling is a difficult task for researchers. The absence of past fire event details makes it tedious to explain the link between fire and vegetation diversity.

2.2 Topography

Fire behavior is quite highly influenced by topography as it is usually static with a time scale (Chowdhury and Hassan 2015). Topography which includes aspect, elevation, and slope, affects fuel and weather change which regulates the spread of forest fire accordingly (de Belém Costa Freitas et al. 2017). A steeper slope accelerates the rate of ignition and fire spread increases toward a higher slope. In the northern hemisphere, the south and southwest aspects provide favorable conditions for fire ignition due to high fuel temperature, lower humidity, and higher sunshine period (Mclauchlan et al. 2020). Lower chances of forest fire in higher elevations are affected by precipitation, wind direction, and speed. Extreme human activities and changing land-use patterns can accelerate a forest fire.

2.3 Climatic Condition

Recent climatic variations as a result of the global climate change phenomenon are extremely conducive to the ignition of fire (Fox et al. 2015; Davis et al. 2017; Briones-Herrera et al. 2019). Climatic variables that affect fire regions show temporal variations ranging from short-duration weather to climatic change over centuries. On a global scale, fire weather index prediction shows around 33–62% of burnable areas by the mid-twenty-first century in comparison to 22% in 2019 (Abatzoglou et al. 2019). Fire season with a widespread fuel load supports recurrent fire events and spreads over a large spatial scale. Large drought spell or rising temperature, wind characteristic, precipitation level, relative humidity, and moisture content in fuel loaded zone provoke or reduce fire intensity over a region (Fox et al. 2015; Yang et al. 2015; Bui et al. 2016). Favorable climate parameters with fuel restricted or fuel limited zone even have reduced fire events. Antecedent rainfall in a forest ecosystem brings a good flush of foliage, widespread deposition of fuel is made available. Climatic conditions within and across an ecosystem describe changes in the type and structure of biotic components with a shift of climate over temporal scale (Chitale and Behera 2019). Fuel-loaded zone with moisture that is not prone to fire, shift to higher fire risk when there is a rise in a dry spell with restricted moisture content. Fire and climate relationship can be summarized from climatic variables like temperature, precipitation, and change in their pattern which affect fuel availability.

2.4 Anthropogenic Intervention

Human interference in the natural ecosystem influences fire incidents by adding greenhouse gases to the atmosphere leads to global warming, changing land-use patterns affect fuel load structure, composition, and continuity, altering frequency and distribution of ignition sources, and intentional ignition for agriculture as a sole motto (Eskandari and Chuvieco 2015). Studies carried out to analyze fire risk show a positive relation between fire occurrence and human influence index (Eskandari and Chuvieco 2015; Marques et al. 2021). Anthropogenic influences had no significant impact on ignition probability, but they did have a significant positive indirect effect on the likelihood of forest fires through fire policy (Xiong et al. 2020).

In many parts of the world known for the ignition of fire due to the natural cause has been replaced by assertive human actions as input. Fire suppression activities increase fuel load and allow interference of invasion into the non-pyrogenic

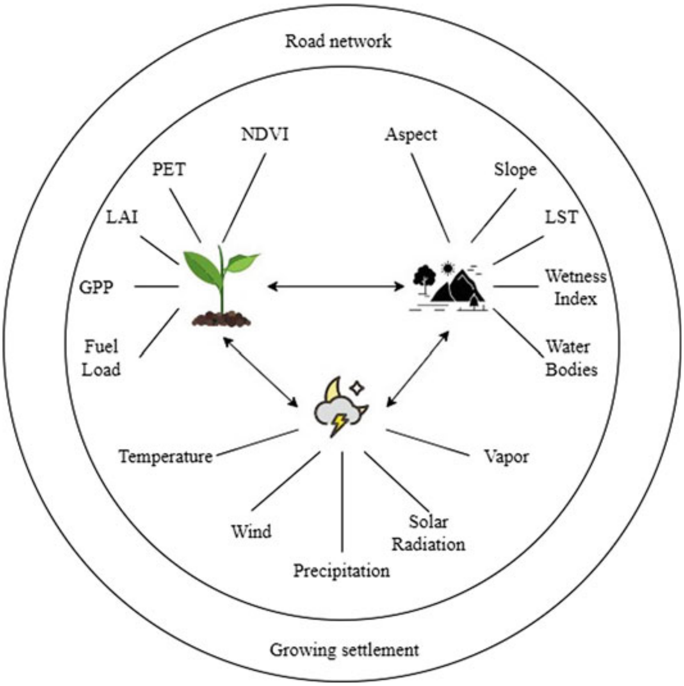

Fig. 2 Factors contributing to forest fire (Inner circle—Natural component, Outer circle—Anthropogenic component)

ecosystem, menacing fire-adaptive ecosystem (Mclauchlan et al. 2020). Anthropogenic impact on the natural ecosystem and climatic change have a greater influence on wildfire, growing duration of fire season (Kauffman and Uhl 1990; Marques et al. 2021). While fuel discontinuity or fuel restriction due to human action reduces fire frequencies accordingly. Land-use change disturbs widespread fuel availability which controls the increase or cut in incidents. It is a major challenge for forest managers to identify anthropogenic influence at multilevel ecosystem organizations with varying socio-economic demands in a region (Fig. 2).

2.5 Changing of Susceptibility in Relation with Factors Contributing

Forest fire incidence, susceptibility, spread, and risk can be understood when ecological and anthropogenic factors relevant to forest fire are known (Adab et al. 2013). Site-specific zonation according to fire susceptibility changes with the change in fire affecting factors. The factors describe fire intensity, severity, the spatial extent of burned area, and lengthening of fire season. Fire prediction studies show a large number of fire events occur in a forest area with a high number of summer days without rain, population size, and topographic features (Boubeta et al. 2015). Different characteristics of fire impact biotic components by affecting establishment, survival, reproduction, and mortality; disturbing ecological interactions (Fox et al. 2015).

3 Ecological Consequences of Forest Fire

Forest fire is a physical force regulating ecosystem and composition at a global spatial scale. From the historical period, it is being evident that forest fire destroys biotic diversity, release captured carbon, and impact climatic condition (Fox et al. 2016). Changing fire susceptibility and frequency interferes with the plant life cycle from the establishment to mortality, developing plant adaptive traits, and introduction of invasive species. Increasing fire activities reduce carbon storage in terrestrial ecosystems and increase global warming making the plant community more prone to fire, changing albedo, and upsurge concentration of GHGs and aerosol. Soil is a relatively large terrestrial carbon pool, nutrient, and microbial source which are highly prone to combustion. Rather than natural components, increasing fire frequency and spread put risk on the socio-economic profile of dwelling communities, disease, and loss of lives (Chowdhury and Hassan 2015).

3.1 Impact on Plant Diversity

Fire and plant diversity are interconnected and directly impact each other. While fuel load and continuity provoke the occurrence of forest fire, post events stimulate ecological succession, development of plant adaptation traits, and provoke global warming by significantly adding up CO_2 to the atmosphere (Eskandari and Chuvieco 2015). This shows fire can alter plant association, disturbing ecological systems. Global warming makes conditions favorable to increase fire frequency and affect flammable species. Fire-plant interaction effects are visible with post-fire species establishment, growth, reproduction, dispersal and seed treatment, crown cover and mortality, and surviving species association (Chitale and Behera 2019). Dry spell with strong wind spread fire over large patch engulfing newer forest not prone to the disaster. Fire suppression encourages plant community establishment and better canopy development. Interaction within plant community and fire has both positive and negative feedback mechanisms. But it is difficult to foresee future climax communities in an ecosystem because of interaction as it varies with changing climate, land fragmentation and encroachment, forest type and structure, invasive species introduction, and prevailing disturbances.

3.2 Impact on Soil Community

Fire may contribute toward soil formation, increasing runoff and erosion which disturb soil nutrients and microbial action in soil (Fox et al. 2016). Recurrent fire incidences, behavior, and spread affect soil structure and composition, altering physiochemical characteristics, organic nutrients, C pool or flux, pyrogenic reaction, and activity of soil biota in comparison to unburnt or control sites. Combustion and pyrolysis destroy upper strata nutrient content while lower layers are also affected by heat flow. Plant communities are the first to show the effect of changing soil characters, further affecting ecosystem structure and function, community. Soil microbial population, biomass content, and mycorrhizal association are infected according to change in fire severity and spread. The effect on the microbial population is persistent over a long period and disturbs the association of microbes within the ecosystem. Recently studies are carried on microbial nutrient content analysis and their association with plant growth, but the focus is needed toward analyzing the synergistic effect of fire and any other disaster like global warming, reduced rainfall, or anthropogenic interference.

4 Susceptibility Modeling and Mapping

Fire prevention and suppression activities followed traditionally proved to be ineffective with Spatio-temporal limitations (Alcasena Urdíroz et al. 2018). Mapping and modeling of forest fire help in the prediction of future incidents, forest managers in taking necessary prevention measures, formulation of fire control policies (Boubeta et al. 2015), and developing fire resilient ecosystems (Alcasena Urdíroz et al. 2018). It focuses on the development of various prediction modes, which explain the challenging pattern of various fire relating variables with a forest fire.

4.1 Fire and Remote Sensing

Using satellite imagery enables researchers to have brief information about a forest fire in remote locations to ecosystems around the globe (Abdollahi et al. 2018). Advancement of temporal and spatial resolution of satellite imagery provides recorded descriptions of recent fire incidences by preparing susceptibility zonation maps (Eugenio et al. 2016). These imageries convey information of geographical coordinates, time, extent, and seasonality which help to analyze the direct links between biotic components and soil properties. Integration of satellite-based remote sensing approach and past ignition records has been proved by researchers to be a successful tool in the prediction of future forest fire events and risk (Abdollahi et al. 2018). It helps to understand the ecological impact, economic damage, and improve strategies toward management planning, fire suppression activities, or fuel treatment (Briones-Herrera et al. 2019). Rather than fire information it also provides precise information about multiple factors regulating ignition, explaining causal-effect relation. Better spatial and temporal resolution and extrapolation of cloud-contaminated images can be deciphered with higher prediction efficiency (Chowdhury and Hassan 2015). Above all aids, the tool is spanning over the past few decades, lacks paleo-ecological facts about the assessment of wildfire regimes and their impact on the ecosystem. The satellite also has other limitations like restricted temporal and spatial extent, characterizing fire intensity, and detecting fire especially active ones. Addressing these challenges would support forest managers and researchers to curb recurrent wildfire and loss of biodiversity.

4.2 Forest Fire and Prediction Modeling

Understanding the need to curb alarming tropical forest fire events, researchers used various modeling approaches to predict future fire events and increased susceptibility of a site with varying ecological factors and anthropogenic interference. Simple to sophisticated modeling approaches are applied to assess forest fires. Some studies were carried out in different regions of the world (Adab et al. 2013; Boubeta et al. 2015; Duarte and Teododo 2016; Bui et al. 2016; Eskandari and Miesel 2017; Bui et al. 2017; Abdollahi et al. 2018; Alcasena Urdíroz et al. 2018; Briones-Herrera et al. 2019; Abedi Gheshlaghi et al. 2020; Bui et al. 2019) to explain factors contributing to forest fire and forecast future risk associated with site-specific. Statistical models fit well with different scales and resolutions of remote sensing data over a large region (Bui et al. 2017). Forest fire susceptibility mapping studies found that modeling using a machine learning approach to be more efficient than weighted models. The application of the machine learning approach generated better results in explaining the complex relationship between forest fire and various factors with higher accuracy (Bui et al. 2016). A study done to assess tropical forest fire susceptibility using Particle Swarm Optimized Neural Fuzzy (PSO-NF) (Bui et al. 2017) was found to perform better than other machine learning algorithms. Kernel logistic modeling was found to be a promising tool for forest fire susceptibility mapping in tropical forest types (Bui et al. 2016). Prediction modeling and mapping of forest fire occurrence from above ground carbon density in different ecoregions could be used for spatial fire occurrence mapping, integrating with GIS tools to estimate fire danger mapping and strategies for proper fuel management (Briones-Herrera et al. 2019). Nevertheless, limitations of remote sensing data over scale and resolution hinder the performance of the machine learning approach and emphasis the development of new prediction modeling to improve prediction accuracy and precision (Fig. 3).

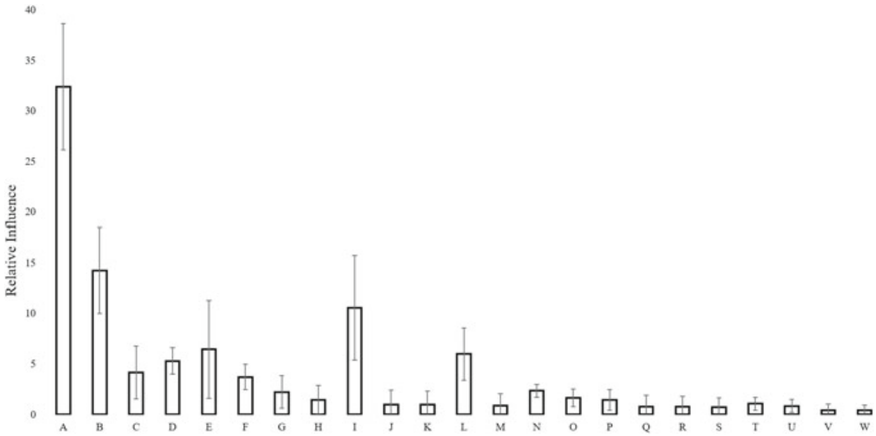

Fig. 3 Relative influence of variables toward the occurrence of forest fire computed using machine learning models (A—Vegetation, B—Temperature, C—Solar radiation, D—Normalized Difference Vegetation Index (NDVI), E—Normalized Difference Water Index (NDWI), F—Elevation, G—Land Surface Temperature (LST), H—Distance from the road, I—Leaf area index (LAI), J—Distance from the settlement, K—Distance from the railway, L—Distance from water, M—Precipitation, N—Wind speed, O—Slope, P—Topographic wetness index (TWI), Q—Aspect)

5 Need of Anticipatory Adaptation Strategy

In general, forest ecosystems have a high capacity for adaptation via community change and natural selection; however, natural processes may be slower than in anthropogenic systems and may not keep up with rapidly changing conditions. Adaptation strategies can either reduce a hazard exposure by containing or controlling it, or decrease susceptibility and increase the capacity to cope, adapt, or benefit from the effects of a hazard (or multiple hazards) through a variety of practices, including those taken before and after impacts are noticed (Devisscher et al. 2016). A proper assessment of risks to ecosystem services, determination of the level of fire vulnerability at the ecosystem and administrative unit, a climate-based early warning system to inform policymakers of high-risk areas, an appropriate incentive and/or penalty scheme to change behavior toward responsible fire use, and sustainable forest management practices in high-risk areas are all characteristics of an anticipatory fire management approach (Kieft et al. 2016). Fire adapted strategies are community-based initiatives that rely on inhabitants to play an integral part in reducing wildfire risk (Steelman 2016). Heterogeneity is also gaining traction as a strategy for enhancing ecosystem resilience. Diversity of vegetative type, stand structure, and successional age classes, as well as patch mosaic burning, have been advocated for biodiversity conservation. Further adaptation strategy is risk management, which employs assessment, mitigation measures, and forest fire inhibition practices to reduce the loss of structures, economic and ecological values of forests due to wildfire (Spies et al. 2014).

A major challenge in encouraging adaptation in fire-prone landscapes is the juxtaposition of a forest ecosystem that is dependent on ephemeral damage and regrowth of biomass, local plant and animal populations, and an anthropogenic system that prefers structural strength, predictability of socio-economic complexities, and potential human protection (Spies et al. 2014). Feedback between the natural and human systems is a crucial barrier to understanding, modeling, and developing adaptive behaviors in fire-prone landscapes. Policies, strategies, and programs may be adopted at different administrative levels to create consistent incentives for action, but institutionalization may take a long time (Steelman 2016).

6 Future Scope

Fire is a complex process in a forest ecosystem regulated by various factors. More carbon in the atmosphere, higher temperatures, less snow, lower humidity, more extreme fire, changing landscapes, more values at risk, more property damage, more fire crews at risk, and more reactive spending are all possible outcomes. Forest fire susceptibility modeling and mapping help to understand how it fits in the present and future socio-ecological conditions and minimize the shift of susceptibility to next higher level with leading changes in climatic parameter or anthropogenic interference.

Our goals should be a predictive forest fire management system that can help to create more socially and ecologically resilient landscapes. Anticipatory fire management would facilitate the identification and implementation of critical actions months before a fire event to minimize the risk of an outbreak. We need policies and practices that are in accordance with the social and ecological realities of such regions where forest fires are anticipated to be a problem. The way forward requires a multi-prolonged, ecosystem-based, and predictive approach is necessary for long-term fire reduction and sustainable forest management. The fundamental premise of anticipatory adaptation is based on preparedness to respond to potential ways in which future forest fire regimes may unfold. This would assist in climate change adaptation and disaster risk reduction in the tropical deciduous forests ecosystem in particular and the adjoining communities at large.

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Understanding the Flood Early Warning System, A Case Study of Transboundary Water Governance in the Gandak River Basin

Shams Tabrez

Abstract Flood is one the most common natural disasters on the planet, due to natural factors and as well as human factors. Climate change, tsunami, cloud bursting, poor river management, silting of the river, etc. are the causes of flooding and it impacts heavily on the lives and economies of the affected region. South Asian region during the three decades period of 1976–2005, 943 natural disasters were reported out of which one-third were caused by floods, primarily in the Indus, Ganges, and Brahmaputra basins. People are killed annually by floods in this region. Experience shows that there are problems such as lack of information, proper dissemination system, etc. In this paper, my case study is at Gandak, which is the most devastating river in the Indo-Nepal region. Most of the master drain river originates from the Himalayas and Gandak also flows from Nepal. Gandak is a transboundary river which has to face issues like political tensions, economic development, and power of decision making have stressed the transboundary issues between India and Nepal. Over the period of time flood risk reduction concentrated on the construction of embankments and retention by reservoirs. But attempt to decrease the vulnerability has given minor importance. The early Warning System should be people-centric as mentioned in the Hyogo framework. Flood Early Warning System has evolved significantly but the warnings still fail to disseminate or fail to reach the communities. Being a transboundary river, it has to deal with various transboundary conflicts, such as the lack of coordination seen between India and Nepal while disseminating the information. In this paper, it gives information about how information is shared between Indo-Nepal and further how this information reaches to the ground level on which there is an exploration of the interface between formal and informal early warning systems and identified various strategies for improving the systems which are existed by reviewing the policy document signed between India and Nepal.

Keywords Early warning system · Transboundary river · Gandak river · Formal early warning

S. Tabrez (✉)
Department of Humanities and Social Sciences, Indian Institute of Technology, Mumbai, India
e-mail: shamstabrezjmi5@gmail.com

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1 Introduction

In the current world scenario, flood remains one of the most pervasive and common disasters in the world, caused by both natural factors, as well as human induced or what is now commonly referred to as anthropogenic factors or human induced factors including poor river basin management, improper land use, deforestation, drainage channels, blocking of channels, etc. Floods cause huge loss of life such as humans, livestock, etc., and, have a devastating effect on the economy of the country and society as a whole. It has been found, that the economic losses associated with floods are more than any other disaster. If we talk about the flood scenario in the Asian Region, almost half of the total global flood damages occur here (Tingsanchali 2012). There are various natural factors responsible for causing floods lik climate change, tsunamis, cloud bursts, silting of the river, etc. (Tripathi 2015). Science has revealed that climate change events have happened in the past and will continue to happen in the future, and there will be more extreme instances of floods and droughts in the future (Fisher 1997). The high-altitude regions are particularly sensitive to the changing climate variability and the weather extremes (Patz et al. 2005) so understanding flood early warning-systems is very crucial to study about the transboundary river system. Notwithstanding, the huge corpus of history attached to this area about these devastating recurring floods, and its increasing impact on the lives of the people; local knowledge of flood early warning systems, has drawn limited research attention, especially given the concerns looming over the official early warning systems, which have been critiqued for their ineffectiveness (Stefano et al. 2012). In the first World Conference on disaster and climate risk management, Early Warning Systems (EWS) has been declared of utmost importance to reduce the disaster risks by all governments and stakeholders. EWS is an important part of disaster management. UNISDR defines EWS as “The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and insufficient time to reduce the possibility of harm or loss”. Alessa (2016) argues that for effective EWS, it needs to be owned by the community, not by the institutions and people should be the primary stakeholders (Alessa et al. 2016).

India is prone to multiple hazards all across the year. Due to its vast geographical expanse, across different climatic zones, it is vulnerable to different types of disasters. During the period of 1915–2015, India had faced about 649 disasters, out of which 302 disasters were caused due to the floods; which makes an average of at least 3 floods per year. This is clearly indicative of the high frequency of floods in our country.

According to the report of the Rashtriya Barh Ayog (1980), nearly 12% of the land in India is vulnerable to floods, which amounts to nearly 40 million hectares of land. Bihar is one of the worst floods affected states in India. According to the Rashtriya Barh Ayog (1980), 16.5% of the entire flood-prone area, lies in the state of Bihar. About 22.1% of the total affected population in India, resides in this state. The idea about the geography of this state can be gathered through the courses of various rivers which traverse it. Ganga flows from west to east and divides the state into two parts.

Several other rivers flow in this region like the Ghaghra, the Gandak, the Kamla-Balan, the Bagmati, the Kosi, and the Mahananda, and each one of them has its origin in Nepal, lying in the Himalayan Region. All the rivers meet the Ganga on its left bank. Since the rivers originate in Nepal and have a confluence with Ganga, they are referred to as the Transboundary Rivers. Kosi and Gandak are the two most devastating rivers in this region. Gandak River Basin drains Nepal's central region. It lies between the river basin of Koshi and Karnali. This river basin has a total area of 34,960 km^2, out of which almost 15% is Annapurna and Dhaulagiri, as well as according to some conservative estimates, about 338 glacial lakes. The Gandak is one of the four snow-fed Himalayan Rivers of the GRB in Nepal and is fed by seven major tributaries namely the Trishuli, Budhi Gandaki, Marsyangdi, Seti, Daraundi, Madi, and Kali Gandaki. It is known as Narayani in Nepal. The Gandak River flows to West Champaran from Nepal, and it finally joins the Ganga west of Patna in India.

The length of Indian rivers and their complex transboundary nature have made it difficult to forecast information and to disseminate it to the last mile. Both the upper and lower streams have their own set of problems. Hence, it becomes really important to understand the flood early warning system in the Transboundary water governance system.

The overall objective of this study is to review the current practices on flood early warning systems across the border of neighboring countries and identify the challenges, potential and prospects of the system that need to be considered, addressed, and harnessed at various levels of coordination and collaboration between the countries, while scaling up and scaling out EWS at regional and trans-border levels.

2 Methodology

2.1 Objectives of the Study

Objective 1: To understand the transboundary flood early warning system for Narayani Gandak River Basin

Objective 2: To understand the flood early warning system in the Gandak river basin from a historical perspective

Objective 3: To explore the interface between the formal and informal flood early warning system and identify strategies for improving the system.

2.2 *Research Design*

Qualitative Research

The paper has been analysed using qualitative research as it occurs in a naturalistic setting and helps in understanding the subjective reality of the participants from their perspective and lived experiences. Qualitative research methodology looks at how an individual constructs reality, the meaning they attach to their reality and interpreting the experience of reality.

The Case Study Approach is used to understand the flood early warning system in the Transboundary Water Governance at Gandak River Basin. It provides an in-depth understanding of the Gandak river basin with a special focus on flooding.

2.2.1 Universe of the Study

The study has been carried out in Bihar at West Champaran district. The main reason behind choosing this area has been that it is one of the most vulnerable regions due to floods.

2.2.2 Sampling Method

The data have been collected through a non-Probability sampling method, where the Purposive sampling technique has been used by the researcher.

The sample size constitutes 8 panchayats in 4 different blocks of West Champaran. Two panchayats are selected from each of the blocks. From each of the panchayat, the respondent is the Electoral Representative of the panchayat which includes either Mukhiya or Sarpanch of the panchayat.

2.3 *Methods of Data Collection*

(I) **In-depth Interview Method**

The researcher used an In-depth interview method which helped in having a direct interaction and allows personal communication between the researcher and the participants. In this method, the researcher collects data from the electoral representative such as Mukhiya, Sarpanch, Panchayat Samiti and Ward Member as they have the lived experience of floods and are directly responsible for the government's policies that are implemented at the panchayat level. The in-depth interview method has also been used to collect data from Engineers and Bureaucrats such as Gandak Barrage Chief Executive Engineer, Project manager of Lutheran World Relief and Water Resource Development Engineer.

(II) **Focus Group Discussion**

Focus Group discussion has been used to collect data from the panchayat community to understand the problem of dissemination system to the last mile person and what would be the best strategies to resolve the problems related to flooding forecasting and flooding in a comprehensive manner.

(III) **Oral History**

The oral History method has been used to collect data from the elderly people to understand the oral history of the Gandak river basin and the traditional early warning system as well as the different practices which are done for flood early warning.

2.3.1 Tools of Data Collection

When a study is conducted by the researcher it is very important to find out a tool for data collection which can help in providing an in-depth understanding of the social phenomenon. Therefore, for data collection in this study, the researcher used a Questionnaire. A separate Questionnaire was formulated for Nodal Officers at Gandak Barrage, for elderly people as well as elected representatives of the panchayat.

3 Data Analysis

The voices of the participants were recorded with the help of a mobile. The next step was to convert this data into a word file for transcription. Coding was then highlighted from the transcription. All these data were fed into the Atlas-TI software. After the completion of coding, categorization was made. From the different categories, themes were identified according to the objectives of the study.

4 Results and Discussion

4.1 Historical Perspective of Flood Early Warning System in Gandak River Basin

The Ganga River has a tributary called the Gandak River. It originates in Nepal and flows into India. This river is also known as the Kali Gandak and Narayani. The river originates in Nepal and enters India at Valmiki Nagar. It then travels across Bihar's immense Gangetic plain before merging into the Ganga around Hajipur or Patna. The Gandak River is a tributary of the Ganga River on its north bank. The watershed area of the Gandaki River is 46,300 sq km, with 7620 sq km in Indian territory.

The Gandak Barrage authorities monitor the water due to the construction of the barrage. They must communicate information as soon as possible. This information is only released to the public during the monsoon season. The water is frequently measured by Gandak authorities between the hours of 01 and 02 a.m. They follow a method in which they collect 01 L of water in a bucket, filter the water, and then collect silt. Because Gandak originates in the mountains, it carries a lot of silt that has been dissolved in the water. There is a method for determining how many grams of silt are in the water. Which situation takes precedence if the silt content exceeds 3.114 g or the water discharge exceeds 02 lac cusec? They analyse the situation and close the canals when the amount of silt exceeds the desired level. They must ensure that only silt-free water reaches the fields. This procedure is used to keep the field free of silt, which harms the crops. Their goal is to keep silt water out of the fields.

Gandak is noted for its erosional features, as is well known. The river was once enormous, but it has shrunk in size as a result of the "katav," which has also caused a change in the river's course. In the previous 15 years, people have had to rehabilitate two to three times. This river's flow has varied by 02–03 kms since 2004–2005. Many villages were moved as a result of its effect, but there is no longer any form of katav.

4.2 Traditional Early Warning System

The local Knowledge system used by the communities or people for climate change adaptation came from experiences and accumulation of experience. These all systems are informal, but the information is passed from one generation to another generation, as from the past local community and acts as a guardian of the whole environment. Local knowledge is often based on place-specific experience, so it provides specific information on climate change, so local communities can provide better inputs in decision making (Srinivasan 2004). The knowledge of the people who live in a certain location and are practicing since time immemorial is referred to as traditional knowledge. From earlier times, the river has always been regarded as the most dependable indicator for flood prediction. Local communities acquire knowledge from past weather events. People observe plants, animals, celestial bodies etc. for prediction. Elders observe the lunar phases and movement of the constellation. The study conducted by Rancoli et al. (2011) in Burkina Faso reveals that indigenous knowledge on rainfall forecasting can contribute towards scientific knowledge, and farmers have successfully used both to predict rainfall forecasting. In the finding from the research conducted in Nigeria (Danladi et al. 2018) the researcher grouped the indigenous flood signs into 3 types which are nature, water and weather. Signs like trees shading leaves, unusual animal (frog) behavior reported flood, water increment in the river is also considered as a sign of a forthcoming flood, increase rainfall also warns people of the flood. According to Mishra (1997), in ancient times also people used to rely on observational skills to predict the changes in the atmosphere, e.g., cloud formations, and biological and phenomenological indicators.

Flooding in the Gandaki River was dubbed as ‘Baad’ by locals. To comprehend early warning, there are various sorts of local knowledge. They contain phenomenological markers such as Halla (Noise), which occurs when the water level rises and the villager begins to shout. They communicate with each other through shouting. This is done in an emergency and is interpreted as a warning. People build machans in this area to protect themselves from floods.

Machan is an elevated bamboo structure used in this location for its safety as well as the safety of the grains. People who swim or bathe in water are acutely aware of the flow of water changes. They avoid swimming when the flow of water begins to shift. It represents the release of water from the Gandak Barrage. During this time, they raise an alarm and inquire about the situation from relatives who live upstream of the Gandak River’s courses. People in this area are also well-versed in weather indications such as wind, clouds, and rainfall.

Elderly people study the movement of the wind by analysing the west wind (purbi/purba hawa), as it is a reliable sign of impending rain. They also looked at the colour of the water, which they dubbed “chamak” (shine) since it shows that the water is coming from Nepal. They can forecast the water level by looking at the river’s edge, or kinara. Locals had a strong understanding of water levels because they were familiar with safe and dangerous levels. When the water level rises above the safety level, people expect a flood. For water measurement, some of the locals planted ‘khuta,’ or bamboo poles. They can analyse the change in the river’s water level in this way. People in this area formed their expertise by measuring the amount of water or analysing meteorological conditions using indigenous knowledge passed down from generation to generation.

4.3 Information Sharing

The Department of Hydrometeorology Information (DHM) shares information about real-time water discharge in Nepal via their website. The data indicates if the flood level is normal, dangerous, or extreme. In India, the Gandak Barrage wirelessly transmits data to the Water Resource Department. After receiving the information, this department must distribute it to the other engineers and the SDO. They must follow the correct procedures and send a copy of the information to the SDO, DM, and other relevant departments.

The information is subsequently distributed to the elected representatives from the concerned departments and government officials. However, the study’s findings demonstrate that the village’s elected representative receives information through the newspaper and radio. They are given information on the amount of cusec water that will be discharged from the barrage. The elected representative rarely receives information from the police station or the block. Some elected officials, on the other hand, acquire their information from the Block or the police, indicating that there is a communication breakdown at the bottom level.

When it comes to the people and the community, they learned about the water discharge from the newspaper, radio, mobile phones, and television. As a result, people are not receiving information from the elected official. It demonstrates that they are at risk due to a lack of an appropriate distribution mechanism in the event of a flood. Even if they are aware of the flood months, they are powerless to stop it. People in Jaralpur village must rehabilitate regularly. As a result, they build residences temporarily. The severity varies by category; the poor suffer the most as they have to live in the same location regardless of their circumstances.

4.4 Means of Dissemination Used for Flood Early Warning System Between India and Nepal

Technology plays a significant role in the dissemination of information from one location to another. Nepal shares statistics from the Gandak river basin via the DHM website. It provides flood warnings. In India, the CWC has around 500 wireless stations for transmitting real-time data relevant to flood forecasting. As a result, when Gandak authorities receive this information, it is forwarded to the Water Resource Department. Landline communication, such as by phone or telegram, has been widely utilised. Flood forecasts are also sent to All India Radio (AIR), and for a broader audience, Doordarshan and local newspapers play an important role in spreading information in the affected area.

The Gandak barrage authorities also use Wireless to transmit information. Official flood early warning letters are issued by the Gandak Barrage authority, and these letters are also sent to concerned Water Resource Department officials and government officials. Flood forecasting is also aided by social media, particularly through platforms like WhatsApp.

4.5 Challenges in the Formal Early Warning System

4.5.1 Transboundary Issue

India is forced to rely substantially on the Department of Hydrometeorology's data. The Gandak barrage is located in Valmiki Nagar, while the nearest rain gauge station is in Nepal's Narayanghat. Valmiki Nagar is 150 kms away from this site. When water travels from Narayanghat to Valmiki Nagar, it undergoes numerous modifications. Valmiki Nagar is situated on mountainous terrain, and the flow of water alters as it passes through. DHM updates flood forecasting on its website, however, the barrage is only watered after 06–07 h have passed since the notice was displayed. Therefore, response to the flooding is hampered as Nepal is situated in a hilly location, disseminating knowledge is usually a difficult process.

4.5.2 Challenges at National Level

Valmiki Nagar is a backward region in Bihar, situated at the farthest reaches of the state. In this region, the government has been unable to deliver essential amenities such as education, medical care, transportation, and communication. As a result of the network problem, spreading information has been a big challenge. Gandak barrage authorities usually rely on Nepal's network for communication. Even in twenty-first century India, bicycles are utilised to disseminate information.

According to the findings, a government official arrived in July to measure the water level, analyse, and assess the damages. Following this early assessment, they only provide compensation in the form of wheat, rice, and other edibles. The government never provides any kind of orientation to the communities, and there was no training provided at the community level during the disaster. The community must respond on their own because they were not given advance notice of the flood. During the rescue and relief efforts, people are also discriminated against depending on their caste.

A family member of an elected representative receives the most benefits from government help, which they do not share with the local community, further marginalising them.

4.5.3 Challenges in the Informal Early Warning System

The communities when they hear that the discharge of water is more than three lakh cusecs from Gandak barrage through newspaper or radio, they start to prepare themselves to tackle with such devastation. Now after the construction of the Barrage, rainfall did not remain the sole criteria for flooding in this area. The nature of flooding over the period has been changed. There have been changes in the pattern of monsoon due to climate change as it shows uneven rainfall during the monsoon period as a result people's traditional knowledge system in responding to the flood has not been very effective.

4.6 Strategies to Address the Challenges

The significance of effective communication during an emergency is a key task. These could be only possible with the robust connections with the organizations and last mile connectivity. This information should be based on reliability and accuracy. The information forwarded by the organization should be clear and easy to understand. Agencies like Lutheran work for the dissemination of information and capacity building. They have village-level committees both in India and Nepal. They focus on 4 basic components of the Early Warning system i.e., Risk Knowledge, Monitoring and Predicting, Disseminating Information and Response. In each village, they have four task forces which works are assigned as Relief, rescue, early Warning

Information and first aid. This people participation approach with their cultural and local knowledge has been an effective solution. Government should partner with these NGOs and provide them data for effective ground reach that will ensure more reliability and accountability.

Government should intervene with a people participatory approach where People from each village should be given responsibility for the different tasks during and after an emergency. There should be different group members for different tasks. Each task force should have good knowledge of their task. It could be possible only through workshops and training of people in the community which can be funded by the government.

In today's scenario, the role of social media, mobile and the internet has become a key source of information. Electricity is also one of the biggest problems in this remote area, so people are still dependent on the radio. As there is a network issue, so instead of using telephone, landline or mobile phone they can use wireless for the dissemination of information.

Social Media can be a very effective medium to disseminate information through WhatsApp. The disaster management authorities should educate people about the local vulnerabilities and make them aware of how to protect themselves from the vulnerabilities arising due to flooding. Early warnings if implemented effectively can save people money, livestock and grains.

5 Suggestion

Flood early warning studies should be taken into consideration in understanding the risk as to the most critical part of a flood early warning system. There is a need for risk assessment research as well as risk knowledge. The construction of the Gandak barrage increases the susceptibility of one village while simultaneously reducing the vulnerability of other communities, as shown in this analysis. A proper risk assessment and risk monitoring procedure should be followed, and there is a need for better cooperation on both sides.

Transboundary areas are always confronted with numerous issues, necessitating the development of a holistic strategy to better understand flooding to improve both structural and non-structural mitigation. The formal practice of sharing information at the ground level or to last mile persons from the top level to the bottom level is exceedingly rare, according to this study. As a result, the governments of these two transboundary nations must reach an agreement on some basic points, as well as the empowerment of local leaders and authorization for such communication concerning agriculture. Various methods of dissemination are seen in this study; however, the information does not reach the intended audience. Therefore, correct linkages should be built to strengthen the dissemination of the system's methods.

6 Conclusion

This paper contributes to the understanding that a flood early warning system is a key component in minimizing disaster risk. Because it has such a large potential for reducing the effects of disaster risk. The international dimension of understanding flood early warning systems in transboundary water governance between India and Nepal is covered in this paper. It demonstrates how information flows from the top to the bottom. Both India and Nepal have established institutional structures for knowledge transmission. Despite the government's institutional setup, information remains out of reach for those living in distant places, according to this study.

It was also observed that people in this area were dissatisfied with the government's efforts on the ground. This research also explains why a community-based early warning system is crucial for mitigation. For this, the Lutheran World Foundation's work examines which organizations collaborate with communities, and its motto is "people-centric." According to the findings, a flood early warning system is extremely beneficial in reducing the risk of flooding. There are institutional arrangements in place, but the efforts of local NGOs, community members, and indigenous knowledge are also critical in limiting the disaster's impact in this flood-prone area.

It also includes people's indigenous knowledge, which they have inherited from their forefathers and which still has the same meaning for them. People still have a strong belief in traditional knowledge because they get an early warning of water from it. This study shows that the role of the early warning system is critical and that by doing so, the community's danger can be reduced. This study also shows how the Gandaki River evolves through time. This location is not only subject to flooding from the Gandaki River Basin, but also from seasonal rivers that create flash floods in this area.

After the construction of the Gandak Barrage, changes in people's livelihoods occurred, as well as changes in the population's vulnerability level; flooding was reduced, while some areas became more vulnerable. This study addresses the obstacles that occurred during the dissemination of information, such as a network issue, elected representatives' irresponsible behavior, prejudice, and the formal organization's hierarchical structure. The information must be disseminated from the top down and through many routes, which causes issues with accountability and authority.

This study clearly shows that the role of social media has grown over time, as people in this location have become more reliant on these sources as internet accessibility has increased in the last 2 years. WhatsApp and other similar platforms play an important role in disseminating information to the last mile population. However, this system has limitations, one of which is the information's reliability. Despite this, it remains one of the most important sources for information dissemination, with government officials now using social media platforms to disseminate information to last mile connectivity. Overall, the findings indicate that the extent and pattern of flooding have shifted.

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Adaptation Policy and Community Discourse of Climate Change in the Mountainous Regions of India

Anshu, Vijendra Kumar Pandey, and Preeti Tewari

Abstract Global climate change is attributed to the increase in greenhouse gas emissions due to industrialisation. Scientists and policy makers are continuously debating on ways to halt global warming. The increasing frequency of disasters as a consequence of this change has had a considerable impact on the livelihoods of people, especially in mountainous regions. Rural communities need to adapt to climate change through adaptation, mainly in their agricultural practices. This paper seeks to examine if there are consistencies in the adaptation programmes of climate change and community response. At the grassroots level, the practical implementation of public policies is thwarted by incoherent and distorted ideologies. Community discourse on climate change is relevant for formulating public policy on adaptation strategies. Diverse ecological and physiographic regions require adaptation policies suited to their unique characteristics. A complete understanding of the adaptation concept requires empirical analysis in different environments. In the present study, quantitative and qualitative methods have been used to understand community response to climate change in the villages of Bhilangana and Bhagirathi basins in Uttarakhand. The study reveals that the involvement of the community is paramount to understanding the adaptation discourse and processes to be undertaken for making policy decisions. There is a need for government involvement in the integration of disaster risk reduction strategies and the climate change adaptation measures in this vulnerable Himalayan Mountain ecosystem. Planning for transformation in agricultural practices can succeed only with due consideration for community needs.

Keywords Community participation · Climate change adaptation · Mountain · Public policy

Anshu (✉) · V. K. Pandey
Department of Geography, Kirori Mal College, University of Delhi, New Delhi, India
e-mail: anshubha@gmail.com

P. Tewari
Department of Geography, Shivaji College, University of Delhi, New Delhi, India

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1 Introduction

The earth is known as the Goldilocks planet as it has just the right temperature to allow a large amount of water to exist in the liquid form. This is as much because it is neither too close nor too far from the sun as it is because of the composition of its atmosphere. The presence of certain key gases in the right amounts is crucial in maintaining the energy budget of the planet. That the atmosphere induces the greenhouse effect by retaining some of the heat received from the sun was first suggested by the French scientist Joseph Fourier in the 1820s (although he did not use the term greenhouse effect). In 1859, the Irish physicist John Tyndall identified water vapour and carbon dioxide as the two atmospheric gases responsible for trapping radiation. Towards the end of the nineteenth century, Svante Arrhenius first put forth the idea that the combustion of fossil fuels by humans would release carbon dioxide into the atmosphere in quantities large enough to raise average global temperatures. However, he thought that the outcome of warming would be of benefit to humanity. That the earth was indeed becoming warmer was established in 1938 by Guy Stewart Callender through his study of temperatures recorded over five decades. However, little attention was paid to scientists raising alarm over warming earth. By the 1980s, the problem had assumed proportions so large that it was no longer possible to ignore it. The community of nations responded by setting up an Inter-governmental Panel on Climate Change (IPCC) in 1988. The First Assessment Report published by the IPCC in 1990 confirmed the role of the emission of greenhouse gases by humans in raising global temperatures by 0.3–0.6 °C in the preceding hundred years.

Faced with incontrovertible evidence about the reality of climate change, the focus has now shifted from whether it is happening to how fast it is happening, what its effects are likely to be, and whether we can do anything to mitigate its impact. Some effects have already become evident. For instance, the onset of phenological spring happens earlier than before while the onset of phenological autumn is delayed. Melting of polar and mountain glaciers and the subsequent rise in sea levels too have already been observed. On the basis of inputs from scientists and experts around the world, the IPCC has predicted an increase in the frequency of extreme weather events, leading to loss of lives and livelihoods. They will also threaten food security in vulnerable populations and act as conflict multipliers (IPCC 2021). Rising sea levels will lead to the submergence of fertile coastal lands, displacing large numbers of people as coastlines migrate inland. Changing atmospheric and oceanic temperatures will induce changes in the movement of winds and ocean currents. This in turn will lead to alterations in the spatial and temporal distribution of precipitation. However, our current understanding of the likely effects of climate change is far from perfect, and "unanticipated effects from a globally warmed world will undoubtedly occur" (Raven et al. 2013).

Changes in the form and distribution of precipitation is one of the crucial factor determining the effects of climate change. Though predicting changes in precipitation is more difficult than predicting changes in temperature, some outcomes can be predicted with a reasonable degree of certainty. Warmer air has a greater capacity to retain moisture, but the additional moisture will not be distributed equally across the globe. Redistribution of precipitation will lead to an increased frequency of droughts and floods in different parts of the world. Scientists also anticipate a decrease in the number of rainy days even in areas where the annual average rainfall remains unchanged. This means that more precipitation comes in the form of single-day events, with prolonged dry spells potentially causing more damage to crops, more soil erosion and increasing the risk of floods (EPA 2021). By modifying the hydrological cycle, global climate change creates stress in freshwater ecosystems (Oki and Kanae 2006). Huge reductions in the size of water bodies impact the availability of water for drinking and agriculture. Climate change adversities thus become the cause of the large-scale displacement of populations that lack safeguards against them. By affecting access to education, food, healthcare and safety, such displacement will put the future of vulnerable groups, especially children, at stake. While the impact of climate change will be universally felt by all individuals, the existing and future threats are greatest for people engaged in primary activities such as fishing and agriculture. Alterations in the biophysical conditions that affect the growth of crops will require massive adjustments by farmers if the productivity of farmlands has to be maintained. This means that cropping patterns and cropping calendars will have to change in accordance with changing temperature and precipitation patterns in order to build resilience against climate change.

At the COP 21 in Paris in 2015, parties to the UNFCC pledged to contain the rise in global temperatures by the end of the current century to within 2 ºC of the pre-industrial levels, and if possible, even to 1.5 ºC. The 2 °C target can only be met if renewable sources of energy are developed to reduce the dominance of fossil fuels. At present, renewable energy sources contribute about 25% to the world's energy needs but their use is expanding very rapidly. Technological advancements, increased competition, and support from government policies have resulted in significant cost cutting in the renewable energy sector. The deployment of renewable energy has outpaced other sources of energy. There is a further need to sustain and increase the momentum of growth to achieve the dream of a carbon free world. As action to reduce emissions has thus far been short of targets, it is best to understand the nature of changes and devise suitable adaptive strategies.

2 Impact of Climate Change in Mountain Areas

Fragile ecosystems such as mountains are especially vulnerable to the effects of climate change. In fact, the earliest evidence of climate change has come from these areas. "Many scientists believe that the changes occurring in mountain ecosystems may provide an early glimpse of what could come to pass in lowland environments, and that mountains thus act as early warning systems" (Kohler and Maselli 2009). Increasing temperatures cause the snowline to rise. As snow-covered areas become snow free, the albedo changes and the reduced reflectivity of snow and ice free mountain surfaces will cause more insolation to be absorbed by the earth-atmosphere system. This positive feedback mechanism will cause further warming of the system, exacerbating the impact of global warming. The reduction in snow accumulation zones and the retreat of glaciers will bring changes in the flow of water in snow-fed rivers. This will pose a threat to humans as well as to wildlife. As more precipitation begins to fall in the form of rain rather than snow, the timing of runoff will change. More water will flow into streams and rivers immediately after rainfall while the flow will dwindle soon afterwards. This will significantly affect the efficiency of existing water storage and delivery infrastructure (Summers 2019). River systems dependent on melt water from mountain glaciers provide freshwater to nearly half the world's population, making mountains the water towers of the world. Ten large Asian river systems originate from glaciers in the Hindukush and Himalayas, meeting the water requirements of a fifth of the world's population (UNEP 2016). Changes in the flow of water in these river systems will have severe implications on the lives and livelihoods of people who depend upon them. Some changes are already evident. A study shows that the changing dynamics of the melt water have had a considerable impact on the nature of river flow in the Himalayas. (Bookhagen and Burbank 2010). There may be an overall increase in the stream flows in response to these changes but the effects will vary spatially and temporally across the Himalayas. An increase will be observed in wet monsoon months and a decline in the dry months, thereby impacting the water availability for human usage and agricultural activities.

Climate change will also exacerbate dangers from a variety of hazards. Fluctuations in temperature could cause unseasonal frost which would damage crops. Melting glaciers and permafrost will cause rocks and soil to become loose and prone to displacement, causing rock falls, debris and mud flows. The occurrence of rain on settled ice or snow causes it to melt, increasing the risk of flash floods. Flash floods also result from the sudden release of water from lakes formed by meltwater from glaciers (glacial lake outburst floods). Intense precipitation from towering clouds (cloudbursts) is yet another cause of flash floods. Heavy precipitation also triggers landslides, wreaking havoc in affected areas. A precursor to what lies ahead was witnessed in Kedarnath in Uttarakhand in 2013 when flash floods devastated the area, causing loss of human and animal lives and widespread damage to property and infrastructure. It must be remembered that mountains vary greatly in terms of location, shape, extension, altitude and other characteristics, the impact on each of them will be different. Variations in topography within a mountain will further add complexity to the exact nature of change. However, certain broad similarities exist in the pattern of change. The next section of this paper presents an analysis of changes in climate observed in two important river basins in the Himalayas.

3 Research Methodology

Several studies have highlighted the impact of change in climate on human lives and how communities are coping with this altered scenario through modifications in their livelihood and agricultural practices. The purpose of the present study was to understand these changes in a mountainous region in India, using a mixed methodology in which both qualitative and quantitative data were collected. Uttarakhand, a Himalayan state in India, has great altitudinal variations, making it ideally suited for understanding the impact of climate change in varying settings, and for the formulation of a suitable policy. A detailed study was carried out in the basins of the Bhagirathi and Bhilangana rivers. Five villages were selected from each basin. The selection of villages was done with due consideration for variations in altitude. Residents in the selected villages were interviewed to generate primary data. Questions were designed to elicit information pertaining to strategies adopted to cope with changes induced by climate change. The objective was to study variations in the adaptive strategies devised in villages at different heights as climate change has led to variability in rainfall patterns and the flow of meltwaters from glaciers. The base level survey in these villages helped in the mapping of the community perception. Various Government of India Reports, Reports of Uttarakhand State Government, Census of India, 2011, District Census Handbooks, Uttarakhand, Reports of ICIMOD were also consulted to gain a better understanding of the problem and arrive at appropriate conclusions.

4 Study Area

The state of Uttarakhand was carved out of the state of Uttar Pradesh in 2000 and can broadly be divided into the two geographic regions of Garhwal and Kumaon. Of its 13 districts, four districts have a considerable proportion of plain area. These are—Haridwar, Dehradun, Nainital and Udham Singh Nagar. The remaining districts of Pauri, Tehri, Chamoli, Uttarkashi and Rudraprayag in the Garhwal region and Almora, Pithoragarh, Champawat and Bageshwar in the Kumaon region, have a hilly terrain. Due to variations in physiography and relief, these districts show a great deal of variation in livelihood patterns as well as in agricultural practices (Fig. 1, Tables 1 and 2).

5 Results and Discussion

Altitudinal and physiographic variations in the Bhagirathi and Bhilangana Basins have an impact on the climatic characteristics, water resources and consequently in agricultural patterns in different parts. In order to capture these variations, 10 villages were selected, 5 from each of the two basins. The basins were divided into three altitudinal zones, and at least one village was selected from each altitudinal zone (Table 3).

The residents in each village were asked questions about changes observed in temperature, rainfall, water availability (discharge in rivers and springs) and whether these changes had an impact on their traditional agricultural practices. The findings were analysed and are summarised in the following sections.

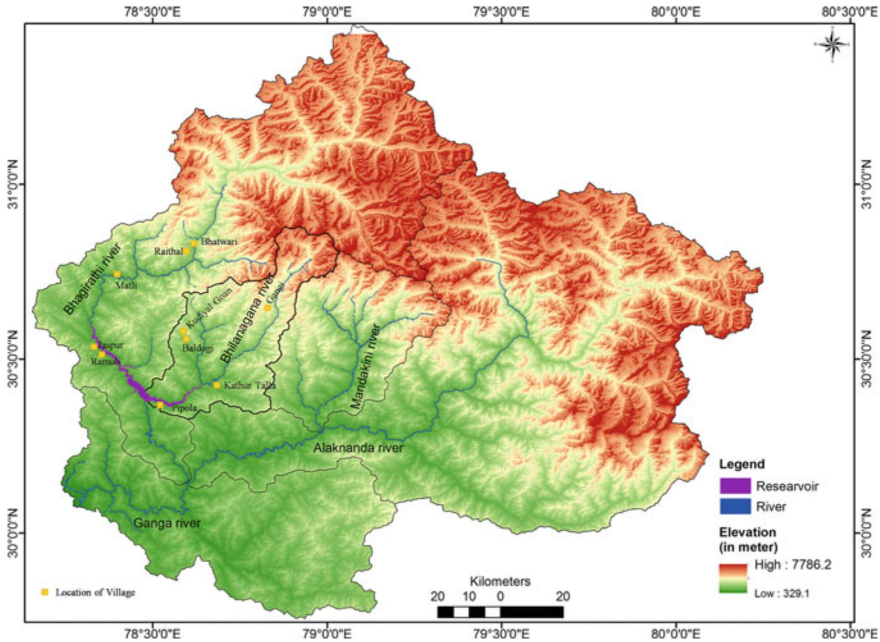

Fig. 1 Study area—location of villages

Table 1 Baseline data of selected villages

District	C.D. block	Village	Area in (ha.)	Population	No. of house holds
Uttarkashi (Bhagirathi Basin)	Chiniyalasaur	Ramoli	67.6	213	51
	Dunda	Jaspur	94.6	453	87
	Dunda	Matali	223.6	3194	651
	Bhatwari	Bhatwari	115.6	1268	279
	Bhatwari	Raithal	375.1	1005	192
Tehri Garhwal (Bhilangana Basin)	Kirtinagar	Pipola	17.6	33	8
	Pratapnagar	Baldogi	60.8	350	75
	Pratapnagar	Kudiyal Goan	41.2	254	46
	Bhilangana	Kathur talla	50.7	446	97
	Bhilangana	Gangi	166.9	386	65

Sources District Census Handbook, Tehri Garhwal, Series 06, Village and Town Directory, Census of India 2011
District Census Handbook, Uttarkashi, Series 06, Village and Town Directory, Census of India 2011

Table 2 Characteristics of Glaciers of Basins

S.No	Basin	No. of Glaciers	Area (km^2)	Volume (km^3)
1	Bhagirathi	374	921.46	13.48
2	Bhilangana	19	112.84	5.98

Source ICIMOD (2001) Inventory of Glaciers, glacial Lakes and Glacial Lake outburst Floods, monitoring and early warning system in the Hindu Kush-Himalayan region, Nepal, (UNEP/RC-AP)/ICIMOD, Kathmandu

Table 3 Physiographic division of the selected villages in the Garhwal Himalaya

Elevation range (in meters)	Bhagirathi Basin	Bhilangana Basin
>2000	Raithal	Gangi
1000–2000	Matali, Bhatwari,	Kudiyal Goan, Kathur talla
<1000	Jaspur, Ramoli	Pipola, Baldogi

5.1 *Rise in Temperatures*

An increase in temperatures has been felt by the people at all altitudes. The common perception across all altitudinal zones is that winters are getting shorter while the duration of summers is increasing. This has resulted in a shortening of the cropping season. For instance, potato now requires only 3–3.5 months to mature as opposed to 5–6 months earlier. On the positive side, this has provided an opportunity for innovative farmers to diversify crops and introduce cash crops such as cauliflower, peas, turmeric and ginger. The disadvantage of rising temperature is seen in the form of an increase in threats from pests and diseases. Previously, traditional methods of pest control such as using cow urine and ash were adequate for countering these infestations but now the use of chemical pesticides has become necessary. In some villages, people complained that new pests had led to more than 50% crop damage.

5.2 *Erratic Rainfall and Water Availability*

Sources of water at higher altitudes include meltwater from glaciers, springs and rainfall. The major concerns expressed were a decrease in winter rainfall, variable monsoonal rain and drying up of springs. Their strategy to cope with the changing rainfall pattern was changing the agricultural calendar. But there was constant uncertainty as there was no stability in the timing and amount of rainfall. Villagers have advanced the sowing of vegetable crops like potato by about 30 days and delayed the sowing of rice by 15–20 days. depending on water availability through irrigation. In case of crop failure due to dry spells, some farmers resowed the seeds while some depended on irrigation facilities. In some villages, they had revived the system of traditional irrigation by joining the water channels through *ghuls*. In some cases, paddy cultivation has been replaced by crops such as soybean, pulses, mustard and fodder grass.

In villages located between 1000 and 2000 m, drying up of springs was turning to be a major cause of water scarcity, especially for domestic purposes. The men have been steadily migrating to the cities for employment, leaving behind women and children. Rain fed agriculture was practiced in the area to raise crops like wheat, potatoes and maize. The villagers spoke about increased risks due to frequent natural disasters including flash floods and cloud bursts. Changes in the rainfall pattern were causing distress due to crop losses. It was also significantly narrated by the villagers that crop productivity substantially decreased over the year. Farmers were keen to shift their agricultural calendar but the adjustment was made difficult by uncertainty in the timing of rainfall. They had observed that winters had now become shorter while summers were not only longer but also warmer. The rising incidences of crop damage by new pests and diseases was another issue of concern. Intermittent rainfall and long dry spells not only threatened agriculture but have also led to an increase in forest fires.

5.3 Socio-economic Considerations and Adaptability

Most areas of this Himalayan zone are experiencing transformation and changes in lifestyle. These have come about as a result of the introduction of new technology in agriculture and the development of tourism. Both have resulted in a heightened demand for water, raising concern in affected communities. In these villages, it was observed that the social and economic characteristics of the population have played a role in the response to climate change and adaptation. Small and marginal farmers did not have access to irrigation and were solely dependent on rain fed agriculture. Farmers with larger land holdings were in a better position to adopt new technology. Large scale male out-migration from the area had led to a feminization of agriculture. Women were shouldering the double burden of household work as well as the care of farms and livestock. It was evident that the impact of disasters and climate change is not gender neutral but is disproportionately greater on women. Special training programmes and schemes need to be designed and implemented to ensure that women are food secure and healthy.

Raithal village, located at an altitude of about 2200 m in the Bhagirathi basin, serves as a base camp for the Dayara Bugyal. The trek to the alpine meadow of Dayara has gained popularity among the tourists in recent times. This quaint village, with a population of 1005 persons, is mainly dependent on agricultural activities. The villagers spoke about the changing climate through their perception of the length of time the snow stayed on the ground. They had observed that the snow cover now lasted for a shorter time. The amount of snowfall has also declined in the last two decades. Moreover, the winters seem to be less severe and the lofty mountains in the vicinity lost their white cover faster than before. According to them, there is a

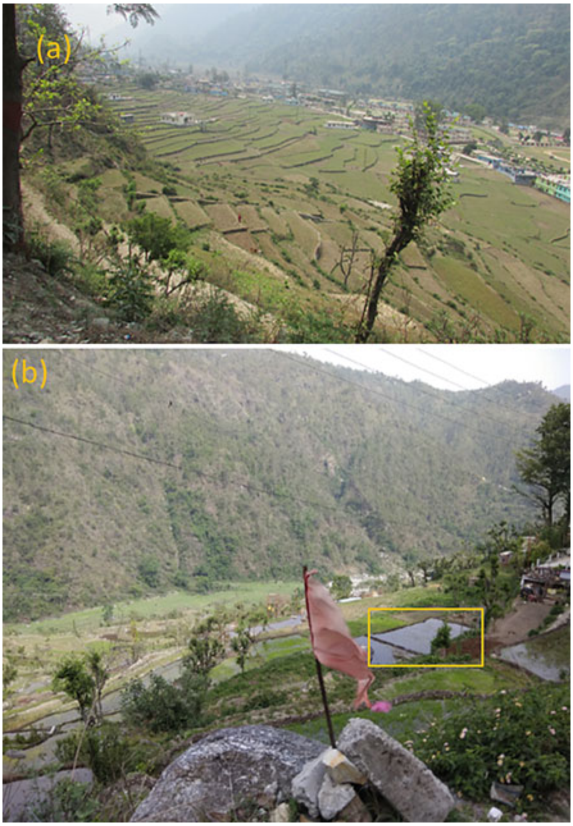

Fig. 2 **a** Terrace farming in broad Balganga Valley, **b** Paddy nursery field raised in 2nd and 3rd week of May

decline in the productivity of potatoes and fodder due to a loss in soil humidity. They attributed this to the shrinking of the rainy season. Their perception too confirmed that winters have shortened and there is an increase in the duration of summers (Fig. 2, Table 4).

6 Conclusions

The changes in precipitation patterns during monsoon have increased the frequency of flash floods and landslides in the study area. Simultaneously, intermittent periods of intense rainfall separated by prolonged dry periods have caused drought in the villages located above 1000 m. The erratic rainfall and frequent hailstorms have severely affected the agricultural productivity and livelihoods of the people living in these areas. The harsh climatic and physical conditions of the mountains present a plethora of environmental challenges for communities inhabiting the mountains. Food security, income security and energy security remain some of the major

Table 4 Nature of risks and variability and adaptations

S.No	Climate change parameter	Nature of risk	Response to risk	Level of adaptation
1	Low rainfall	Water scarcity, low crop productivity	Irrigation: joining of guhl	Community
2	High temperature	Increasing diseases in crops	Greater use of pesticides	Individual
3	High rainfall	Rapid growth of weeds	Increased use of weedicides	Individual
4	Increase in climatic fluctuation	Decreasing productivity, unstable prices	Irrigation—use of sprinklers. Share and use of water resources	Community-individual connect
5	Extreme events-landslides/slope failures/debris flow	Low productivity, soil damage and soil loss	Exchange labour and increased coordination between stakeholders	Community

livelihood issues. Migration is a common phenomenon for mountain communities. However, in recent decades, climate change has added a new dimension to these problems by amplifying existing risks and adding newer ones. Water scarcity has been another major issue in these mountain villages. In many villages, villagers complained that their natural springs have dried up in the last few years. As men migrate towards cities looking for better opportunities in the form of jobs and education, only women, children and the elderly remain in the villages to cope with the new challenges. As a result, women now spend more time looking after their households and also the farmland. There is increased risk due to frequent natural disasters. However, not all the problems in the area are due to climate change. Some may be the result of anthropogenic changes induced in the form of dam construction and road development projects. In the last two decades, an initiative to build rural roads has been ushered in under the Pradhan Mantri Grameen Sadak Yojna (PMGSY). This has resulted in environmental and ecological issues which were not given due consideration at the planning and execution stages. Keeping in view the vast ramifications of environmental changes on all aspects of human life, there is a need to maintain a delicate balance among various players in the developmental process. The incorporation of effective adaptation strategies into local development and policy frameworks is the need of the hour. A multipronged strategy for the agricultural sector is needed in view of the changing climate scenario. The strategy should incorporate various key areas based on which specific goals can be set. It is necessary to carry out scientific research in agricultural techniques suitable for mountain areas. At the same time, traditional practices of sustainable agriculture need to be revived and strengthened in order to increase the resilience of mountain communities to climate related stress. The promotion of organic farming and crop diversification can minimise the adverse impacts of climate change. Early identification of likely trends and dissemination of this knowledge among all stakeholders will give them time to evolve coping strategies. Farmers, for instance, can devise crop practices keeping in view the emerging future thermal trends. Increasing credit to the agriculture sector in areas and practices which are in consonance with the changing physical milieu should be a focus area of the policy. Central and state governments can help by promoting weather and climate resistant crop varieties, increasing crop insurance cover, capacity development, and information dissemination among farmers through Village Knowledge Centres (VKCs). Involvement and close coordination of the community has to be ensured for long term sustainability of any policy.

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Analysis of Public Awareness, Health Risks, and Coping Strategies Against Heat Waves in NCT of Delhi, India

Vedika Maheshwari

Abstract Over the recent years, unparalleled heat waves driven by climate change with more severity, intensity, and frequency have been recorded in Delhi, with 2019 being the warmest year on record. Extreme heat is a serious public health concern and one of the leading causes of weather-related fatalities. The major aim of this study is to examine the awareness and perception of and attitudes toward the heat waves and associated health risk and the coping practices adopted, among a group of residents in NCT of Delhi. A cross-sectional study was conducted during April–May 2020 among the sample of 180 residents of Delhi. Information related to socio-demographic characteristics, knowledge, and awareness regarding heat waves, heat illness history reported during the summer, and the various coping practices adopted to combat extreme heat were collected and analyzed. The results of the survey found that a majority of the respondents (75.6%) considered heat waves a disaster and extreme heat a serious public health risk. It was observed that the main sources from which respondents received information about heat waves were Internet/social media (75.6%) and newspapers (50%). More females considered heat waves a disaster and a serious health risk and were likely to be more informed than males. The main issues that concerned the respondents during the heat wave events were their health, safety of birds, animals and pets, relatives/family/friends, etc. A majority of the respondents felt uncomfortable during a heat wave event. A majority of the respondents (85.6%) experienced a loss in productivity level at workplace. Most of the respondents (53.3%) have also experienced some kind of extreme heat-related symptoms or illness, among which heat exhaustion was on the top. Top coping practices adopted to get protection from extreme heat included using fan/AC/cooler and drinking sufficient water. Such findings may inform the policymakers in reframing and communication strategies for heat waves in Delhi and help people to be better prepared in the event of heat waves.

Keywords Heat waves · Public awareness · Public health risk · Coping strategies · Survey

V. Maheshwari (✉)
Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi, India
e-mail: vedika26.vm@gmail.com

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Abbreviations

HW	Heat waves
HSL	Higher Secondary Level
CHZ	Core Heat wave Zone

1 Introduction

Climate change is driving temperatures higher as well as increasing the frequency and severity of heat waves all across the globe and especially in India (Intergovernmental Panel on Climate Change [IPCC] 2014). According to Global Climate Risk Index 2020, India is the fifth most vulnerable country in terms of extreme weather events and climate change (Germanwatch 2020). Extreme heat is an underappreciated public health hazard (Howe et al. 2019). Heat waves can have a profound impact on large populations for short time periods, often set off public health emergencies (alarmingly high rate of hospital admissions due to heat stroke, etc.) and result in excess mortality, and overwhelming socioeconomic impacts (e.g., loss in work capacity and labor productivity) thereby affecting livelihoods of many people (World Health Organization [WHO] Fact sheet 2018). An increasing amount of scientific research around the world has pointed out that extreme weather events (e.g., heat waves) will become very common as a result of climate change (Easterling et al. 2000). For example, about fourteen record-breaking weather and climate-related disasters were reported in the United States in 2011 which caused economic losses and loss of human life. Included among these extreme weather-related disasters were heat waves and in March 2011, about 15,292 warm temperature records were broken across the USA (Akompab et al. 2012). A heat wave took more than 70,000 lives in Europe in August 2003 (Robine et al. 2008) and it killed about 56,000 people during the 2010 Russian heatwave and wildfires (Trenberth and Fasulo 2012). Diseases related to extreme heat are bound to affect the health of a large number of people at risk, such as the elderly and children, specially abled, women, those who work outside such as construction workers, traffic policemen, farmers, etc. and will likely affect populations across all the age groups in the coming decades (Lee et al. 2019). In many regions of our planet, heat waves are a major public health concern, and dangerous heat wave accounts recorded across the globe have elucidated the health, social, environmental, and economic consequences associated with heat waves (Akompab et al. 2012).

Episodes of extreme heat and heat illness are becoming a recurring phenomena in India (Azhar et al. 2014). During 1901–2018, India's average temperature has risen by around 0.7 °C. By 2100, the average temperature of India is projected to rise by approximately 4.4 °C as compared to the average between 1976 and 2005 (Ministry of Earth Sciences, Government of India 2020). The impact of extreme heat events is likely higher in developing countries such as India given a combination of increasing temperatures from climate change and higher population vulnerability (Azhar 2019). Due to extreme heat, India loses hundreds and thousands of people during the summers every year. For example, Ahmedabad witnessed its deadliest heat wave in the May 2010 and the heat-related death count was nearly 1400 while Odisha lost 2042 people in 1998 heat wave (Azhar et al. 2014; Odisha State Disaster Management Authority [OSDMA] 2017). About 22,562 heat-related deaths were reported between the periods 1992 and 2015 in India (National Disaster Management Authority [NDMA], Government of India 2019). The year 2019 has already witnessed the second longest spell of sweltering temperatures ever reported with a heat wave spell lasting 32 days (Chauhan 2019). India lost 118.3 billion work hours alone because of extreme heat in 2019. India also saw a record number of above baseline days of heat wave exposure affecting people aged above 65 years (The Lancet 2020). Research emphasizing exclusively on India concludes that heat waves will last longer, be more intense, and occur more often in the future (Murari et al. 2015).

As per a report by District Disaster Management Authority [DDMA] (2018), "A Heat Wave is a period of abnormally high temperatures, more than the normal maximum temperature that occurs during the summer season in the North-Western parts of India. Heat Waves typically occur between March and June, and in some rare cases even extend till July."

The Indian Meteorological Department (IMD) has given the following criteria for Heat Waves:

- Heat Wave need not be considered till the maximum temperature of a station reaches atleast 40 °C for Plains and atleast 30 °C for Hilly regions
- When normal maximum temperature of a station is less than or equal to 40 °C Heat Wave Departure from normal is 5 to 6 °C. Severe Heat Wave Departure from normal is 7 °C or more
- When normal maximum temperature of a station is more than 40 °C Heat Wave Departure from normal is 4 to 5 °C. Severe Heat Wave Departure from normal is 6 °C or more
- When actual maximum temperature remains 45 °C or more irrespective of normal maximum temperature, heat waves should be declared (IMD 2020).

The capital city of India, Delhi comes under the Core Heat wave Zone (CHZ) of the country (IMD 2020). Unprecedented heat waves have been recorded in the summer months in Delhi over recent years. In the deadly 2015 heatwave, Delhi recorded five consecutive days with high temperatures over 43 °C (Liberto 2015). The 2019 heat wave was one of India's most lengthy and vigorous heat waves in decades (Mashal 2019). There were 13 heat wave days and 1 severe heat wave day from April to June in 2019 in Delhi (IMD 2020). The city also saw its hottest day on record for the month of June as temperature rose to 48 °C on 10 June 2019 (Bhushan 2019). In the current summer season of 2020, May 22 was the hottest day recorded when mercury levels shot above 45 °C in some parts of the city ("Delhi Experiences Hottest Day" 2020). The rising population levels in Delhi coupled with the increase in greenhouse gas emissions, which lead to pollution and global warming and cause differences in weather parameters like temperature, relative humidity may result in increased instances of heat waves (Singh and Singhal 2019). Moreover, the repercussions of climate change produced extreme heat and heat stress in Delhi will be further magnified by the urban heat island effect. It has been estimated that the number of heat wave days in Delhi is 2.3 times in comparison to the adjoining rural areas (Sharma et al. 2019).

In recent times, there has been an ever increasing interest in understanding public views regarding environmental issues. Many studies have been conducted to analyze the public perception and attitudes toward climate change and majority of these studies have opined that attitudes of public toward climate change have differed over the years (Akompab et al. 2012).

In one study, surveys were conducted in USA, Canada, and Malta to assess the public perceptions of climate change as a human health risk. It was discovered that a majority of people in the three countries considered that climate change poses significant risks on health and wellbeing. However, climate change seems to lack prominence as a health issue in all three countries as only a few people had a clear understanding of the associations between climate change and human health risks (Akerlof et al. 2010).

Other studies have examined perceptions about heat waves of which the majority discovered that some of the participants did not believe that they were exposed to potential consequences of heat waves. For instance, a study was undertaken to examine public perception and attitudes toward heat waves in the context of climate change among a cohort of residents in the south Australian city of Adelaide. It was discovered that despite the fact that heat waves may possibly cause heat-related illness and mortality, less than half (34.5%) of the respondents reported health as a concern during a heat wave, which is a sign that heat waves were not considered as an instant threat to their health. However, results of the study also showed that a considerable proportion of the respondents indicated that there was a possibility that heat waves will escalate in future as per projections by some scientists and that it would be quite sure that if there is an increase in heat waves in Adelaide, it would have grave consequences on people's health (Akompab et al. 2012).

Howe et al. (2019) suggest that "The health effects of extreme heat depend not only on exposure, however, but also on behavioral responses, which are related to perceived risk." A study was carried out to analyze the public perceptions of the health risks of extreme heat at multiple scales across the USA. It was observed that places with elderly populations with heightened vulnerability to health impacts of heat tend to have lower perceptions to risk, thereby exposing them to even greater risk as lack of awareness is a hurdle to adaptive responses (Howe et al. 2019).

In a developing and tropical country like India where heat waves have become a common phenomena and where a lot of people die annually due to water scarcity, a very limited number of studies have been undertaken that have specifically examined public awareness regarding heat waves (Azhar 2019; Akompab et al. 2012).

The Indian capital Delhi has been chosen as the case study for conducting this research because of the increasing occurrences of heatwaves in the past few years. Hence, it is a prime example for investigating the potential impacts of heat waves in urban areas and its residents. Despite the fact that heat waves are one of the crucial hazards which endanger the city and there have been surging cases of mortality and morbidity in relation to vulnerability to extreme levels of temperature and relative humidity in recent years, the government of Delhi has still not devised a detailed heat action plan to tackle the risks arising from extreme heat (Chaudhary 2018; Singh and Singhal 2019). In comparison to other Indian cities, Delhi is running behind in constructing a heat action plan mostly because of several agencies and inefficient coordination between them (Chaudhary 2018). In addition to this, there is a lack of acknowledgment and awareness of the amplitude of heat stress despite heightened cautioning and forecasting of extreme heat events for the future among the citizens of Delhi, since there is little to no proper form of communication in this matter (Chaudhary 2018). This can have a profound impact on the lives of the citizens of Delhi who have to bear scorching heat every summer and hence, are prone to health risks associated with heat waves. In the light of this, it becomes highly necessary to understand how the residents of Delhi perceive the risks associated with heat waves, how aware they are and how much knowledge they have regarding heat waves, and what all strategies are adopted by them to cope with extreme heat.

Public perception and awareness regarding heat waves are pivotal in policy formulation and can help the concerned authorities and institutions to make Delhi better prepared and ready to face the challenges caused by heat waves in future. It is very important to ascertain citizen attitudes, knowledge, and awareness regarding heat waves in order to save lives, minimize the health impacts caused by exposure to extreme heat and make the public alert, informed, educated, and prepared to face heat waves under ever changing climate through proper communication plans and programs (Akompab et al. 2012).

Therefore, there is a need to examine public awareness, knowledge, health risks, and coping strategies regarding heat waves, as at present, little to no studies have been conducted which have specifically focused on this theme in India. The specific objectives addressed by this study are as follows:

(1) To observe the perception, awareness, and attitude of the general public toward heat waves and heat related illness.
(2) To understand the associated health impacts.
(3) To identify the coping practices and techniques adopted for protection against heat wave risk.

2 Study Area

Delhi is the National Capital Territory of India. The territory is surrounded from three sides by Haryana and from the east side by Uttar Pradesh. The latitudinal and longitudinal extent is 28.24–28.53 North degrees and 76.50–77.20 East degrees, respectively. The area covered by the territory is 1,483 km^2. Delhi has a total of 11 districts with 33 Tehsils/Sub-Divisions. With an urban area of 1113.65 km^2, it is the largest metropolitan city in India (Planning Department 2019). According to the 2011 census of India, the population of NCT Delhi stands at 1,67,87,941 (ORGI 2013) (Fig. 1).

The climate of Delhi is semi-arid (Department of Environment 2017). Delhi experiences extreme weather conditions (Singh et al. 2005). In 2017, the range of mean maximum monthly temperatures was from 9.1 °C in January (winter) to 40.1 °C in May (summer) (Department of Environment 2017). The monsoon season in Delhi is between July and September. The annual rainfall reported in 2017 was about 779

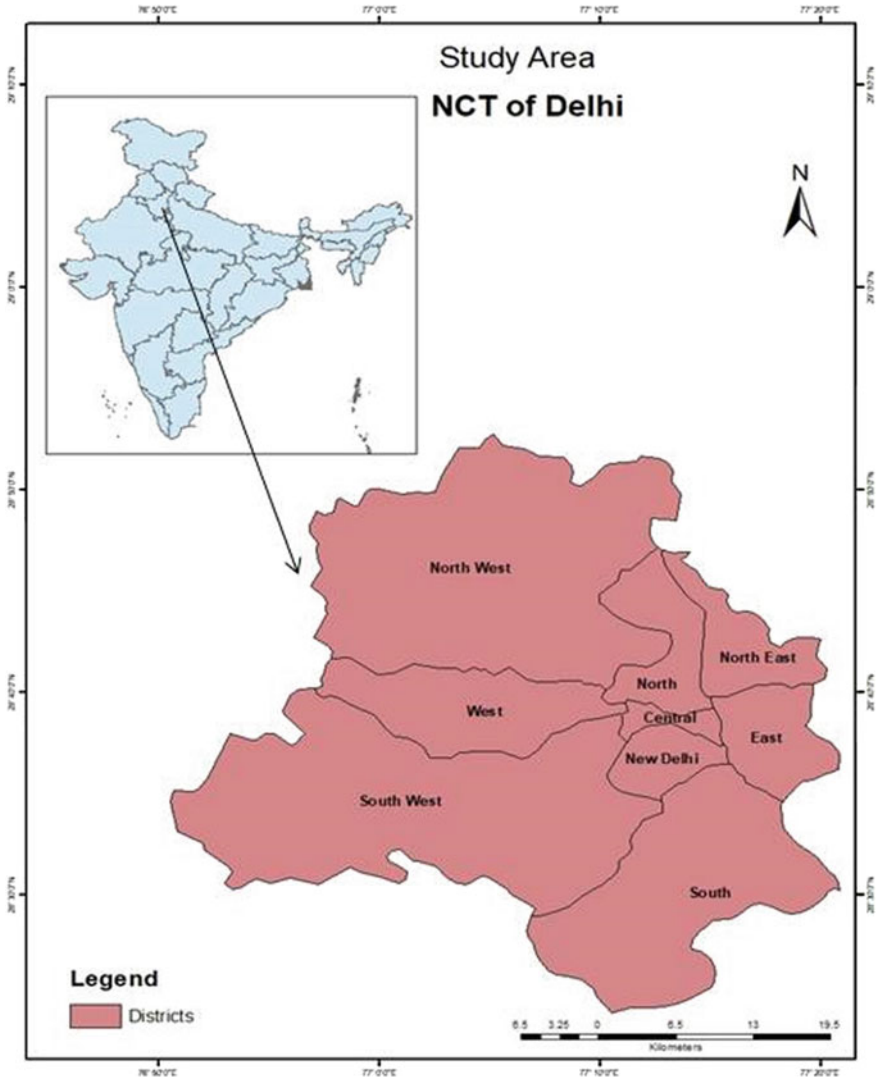

Fig. 1 Study area (NCT of Delhi)

mms, out of which 583.4 mms was recorded during the monsoon months (Department of Environment 2017). High humidity levels persist during this time (Singh et al. 2005). During the pre-monsoon and summer months, dust storms are a frequent phenomena experienced in Delhi which lead to the accumulation of particulate matter in the atmosphere (Department of Environment 2017).

3 Research Methodology

For the purpose of conducting the survey to analyze the perception, awareness, and attitude of the general public toward heat waves and the associated health risk as well as the coping strategies adopted against heat waves, a questionnaire was framed with the help of Google Forms after a careful review of literature related to heat waves, perception, awareness, and knowledge regarding heat waves and the associated health impacts and the coping practices adopted during a heat wave event. Few questions and response options were informed by previous surveys on public attitudes toward climate change. However, efforts were made to adapt all the questions to the context of heat waves with some questions having both closed and open-ended responses.

Primary data acquired from the online questionnaire survey of 180 residents of Delhi, related to their socio-demographic characteristics, knowledge, and awareness regarding heat waves, heat illness history reported during the summer, and the various coping practices adopted to combat extreme heat has been compiled, analyzed and discussed. To ensure that the hot weather was salient to respondents at the time, the questionnaires were deliberately e-mailed during the summer months of April–June in the year 2020, when the temperatures were mostly above 35 °C.

There are three main parts of the questionnaire survey:

(a) Socio-demographic information of the respondents.
(b) Perception, Awareness of, and Attitude toward Heat waves and associated health risk.
(c) Necessary Coping practices and adaptation strategies during heat wave days.

For data analysis, the data were entered into MS-Excel Spreadsheet where descriptive analysis was carried out. After a thorough analysis and interpretation of the collected data, the major results, observations, and findings, data has been presented in the form of tables and figures like bar diagrams, etc. for easy understanding.

4 Results and Discussion

4.1 Socio-demographic Characteristics of Respondents

Table 1 shows the selected socio-demographic characteristics of respondents.

Table 1 Background profile of study respondents

Respondent characteristics		
Variable	Number	Percent (%)
(1) Age		
6–15	5	2.8
16–30	147	81.7
31–45	14	7.8
46–60	12	6.7
Above 60	2	1.1
Total	180	100
(2) Sex		
Males	80	44.4
Females	100	55.6
Total	180	100
(3) Level of education		
Educated at or below higher secondary level (HSL)	16	8.9
Educated above higher secondary level*	164	91.1
Total	180	100
(4) Level of employment		
Professional	34	18.9
Salaried	46	25.6
Homemaker	10	5.6
Student	89	49.3
Retired	1	0.6
Total	180	100
(5) Annual household income		
<2,50,000	26	14.4
2,50,001–5,00,000	40	22.2
5,00,001–10,00,000	55	30.6
>10,00,000	59	32.8
Total	180	100

Source Primary Survey, April–June 2020 * Referred to those who pursued higher education after school (e.g., bachelor or postgraduate degree)

Majority of them (81.7%) belonged in the age group 16–30 years. More than half of the respondents (55.6%) were female. In terms of level of education, majority of the respondents (91.1%) pursued higher education. Majority of the study respondents (49.3%) were students. Most of the respondents (32.8%) earned a household income of above 10 lakhs per annum.

4.2 Awareness About Heat Waves

To check their knowledge and awareness level about heat waves, respondents were asked whether they considered HW a disaster or not, whether extreme heat posed a serious health risk or not, the level of information about HW, degree to which information about HW is followed and sources from where they obtained information about HW.

Respondents were questioned about the information sources regarding heat waves. It was observed from Fig. 2 that Internet/social media (75.6%) was the top most information source, followed by newspapers (50%) and television (45%). Apart from these, radio (3.9%) and getting informed through a family/friend (12.2%) were some other common sources. Books, informative magazines, newsletters, leaflets, and brochures are some other sources (7.2%) from which respondents acquired news about heat waves.

Table 2 shows how the knowledge and awareness about HW varies with respondents background characteristics. Overall, majority of the respondents (75.6%) considered heat wave a disaster and extreme heat (92.8%) a serious public health risk and hazard, which is a good sign of awareness. More than half of the respondents (54.4%) cited being moderately informed about HW, followed by those who were strongly informed (22.2%). Rest of the respondents were either slightly (20.6%) or not at all informed (2.8%). Nearly half of the respondents (46.7%) indicated that they followed information about HW moderately, 15.6% followed information strongly, 32.8% followed information slightly, and 5% indicated that they do not follow information about heat waves at all. It was observed that most of the respondents across all age groups considered HW a disaster as well as extreme heat a serious public health risk, with majority of respondents in the age group 16–30 years considering HW a disaster (76.9%) and extreme heat a serious public health risk (93.9%). More females (80%) than males considered the same. Respondents, whether educated below (75%) or above (94.5%) HSL believed that extreme heat posed a serious health risk. However, they were not sure whether they can consider HW a disaster or not. Majority of the respondents from working to homemakers or

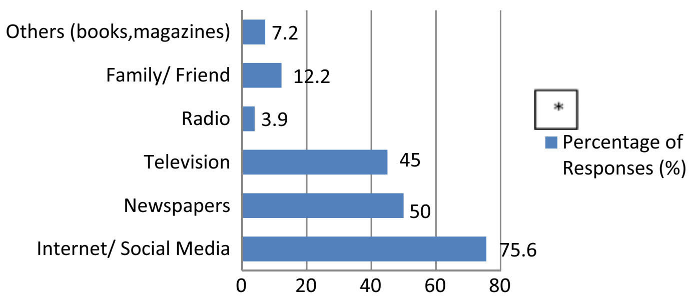

Fig. 2 Sources of information regarding heat waves. * % total may add up to more than 100% as multiple responses were permissible

Table 2 Awareness about heat waves by respondent characteristics

Respondent characteristics	Consider HW a disaster				Consider extreme heat as a serious public health risk				Level of information about HW					Degree to which information about HW is followed				
	Yes	No	Maybe	Total	Yes	No	Maybe	Total	Strongly	Moderately	Slightly	Not at all	Total	Strongly	Moderately	Slightly	Not at all	Total
Total respondents (n = 180)	75.6	4.4	20	100	92.8	2.8	4.4	100	22.2	54.4	20.6	2.8	100	15.6	46.7	32.8	5	100
(1) Age																		
6–15	40	20	40	100	60	NA	40	100	NA	60	40	NA	100	20	20	40	20	100
16–30	76.9	19.1	4.1	100	93.9	3.4	4.1	100	22.4	54.4	21.1	2.1	100	15	45.6	34.7	4.8	100
31–45	71.4	7.1	21.4	100	57.1	NA	NA	100	21.4	64.3	14.3	NA	100	14.3	64.3	21.4	NA	100
46–60	75	NA	25	100	91.7	NA	NA	100	33.4	41.7	16.7	8.4	100	25	50	16.7	8.4	100
Above 60	100	NA	NA	100	100	NA	NA	100	NA	50	NA	50	100	NA	50	50	NA	100
(2) Sex																		
Males	70	6.3	23.7	100	90	5	5	100	17.5	60	18.8	3.8	100	12.5	47.5	35	5	100
Females	80	3	17	100	94	2	4	100	26	50	22	2	100	18	46	31	5	100
(3) Level of education																		
Educated at or below Higher Secondary Level	31.3	12.5	56.3	100	75	6.3	18.8	100	NA	43.8	37.5	1.2	100	6.3	31.3	50	12.5	100
Educated Above Higher Secondary Level	18.9	3.7	77.4	100	94.5	2.4	3.1	100	24.4	55.5	18.9	18.8	100	16.5	48.2	31.1	4.3	100
(4) Level of employment																		
Professional	70.6	NA	29.4	100	94.2	2.9	2.9	100	20.6	58.8	17.6	2.9	100	14.7	55.9	29.4	NA	100

(continued)

Table 2 (continued)

Respondent characteristics	Consider HW a disaster				Consider extreme heat as a serious public health risk				Level of information about HW					Degree to which information about HW is followed				
	Yes	No	Maybe	Total	Yes	No	Maybe	Total	Strongly	Moderately	Slightly	Not at all	Total	Strongly	Moderately	Slightly	Not at all	Total
Salaried	82.6	6.5	10.9	100	91.3	2.2	6.5	100	19.6	56.6	21.7	2.2	100	13	43.5	37	6.5	100
Homemaker	90	NA	10	100	100	NA	NA	100	30	20	40	10	100	20	30	40	10	100
Student	72	5.6	22.5	100	92.1	3.4	4.5	100	23.6	55.1	19.1	2.2	100	16.9	46.1	31.5	5.6	100
Retired	100	NA	NA	100	100	NA	NA	100	NA	100	NA	NA	100	NA	100	NA	NA	100
(5) Annual household income																		
<2,50,000	73.1	7.7	19.2	100	84.6	11.5	3.8	100	17.9	46.4	21.4	7.1	100	11.5	42,3	38.5	7.7	100
2,50,001–5,00,000	72.5	2.5	25	100	97.5	2.5	NA	100	20	57.5	22.5	NA	100	15	52.5	20	12.5	100
5,00,001–10,00,000	81.8	NA	18.2	100	96.3	NA	3.7	100	30.9	50.9	16.4	1.8	100	20	47.3	31	1.8	100
>10,00,000	72.9	8.5	18.6	100	89.8	1.7	8.5	100	16.9	57.6	22	3.4	100	13.6	44.1	40.7	1.7	100

Source Primary Survey, April–June 2020; NA—Not Available

students considered HW a disaster as well as extreme heat a serious public health risk. 90% homemakers considered heat waves a disaster, followed by salaried (82.6%) and professional (70.6%) respondents. All homemakers and retired respondents believed that extreme heat posed a serious health risk, followed by professional (94.2%) and students (92.1%). Majority of the respondents (81.8%) earning an annual household income between 5 and 10 lakhs, followed by those who earned less than 2.5 lakhs (73.1%), considered HW a disaster. Whereas majority of the respondents (97.5%) earning an annual household income between 2.5 and 5 lakhs considered extreme heat a serious public health risk. Regarding the level of information respondents have about HW and the degree to which they follow that information, it can be observed that majority of respondents were moderately informed about HW, with most of them (64.3%) in 31–45 years of age group, followed by those (54.4%) belonging to 16–30 years age group. Most of those respondents who were moderately informed about heat waves in 31–45 years of age group, followed news or information about them moderately (64.3%) followed by 50% respondents, both in 46–60 and above 60 years of age group. Respondents who had a strong information level about HW belonged to 46–60 age group category (33.4%) and they also followed information strongly (25%). More males (60%) than females were moderately informed and followed information moderately (47.5%) about HW. Respondents, educated above HSL (55.5%) had more information level than those below that level and were more likely (48.2%) to follow information about HW. All retired respondents had moderate information level followed by professional (58.8%) and salaried (56.6%) respondents. They also followed news about HW moderately, followed by professional (55.9%) and students (46.1%). Most homemakers (30%) were strongly informed about HW, followed by students (23.6%) and professional (20.6%) respondents. Homemakers (20%), students (16.9%), and professional (14.7%) simultaneously followed news about HW strongly. Majority of the respondents (57.6%) earning an annual household income above 10 lakhs, followed by those who earned between 2.5 and 5 lakhs (57.5%) were moderately informed. About 7% respondents in income group of less than 2.5 lakhs were not at all informed about HW. Majority of the respondents (52.5%) earning an annual household income between 2.5 and 5 lakhs followed information about HW moderately, followed by those belonging to 47.3% respondents in 5–10 lakhs income group. 12.5% respondents in income group 2.5–5 lakhs did not follow information about HW at all.

4.3 Variability in Perceived Health Impacts of Heat Waves

Respondents were asked a set of questions about how concerned they were about potential effects of HW on their health and society, how extreme heat affects their health, productivity levels, and other associated health risks. It can be observed from Table 3 that in all, a considerable proportion of respondents (47.2%) were "strongly concerned" about the potential effects of HW on them personally as well as on society, followed by those who were "moderately concerned" (40%). Rest of the respondents

Table 3 Variability in perceived health impacts of heat waves by respondents background characteristics

Respondent characteristics	Level of concern about potential effects of HW on society and oneself					Experienced productivity loss during extremely hot days			Whether suffer from any chronic illness			Experienced extreme heat related symptoms/illness		
	Strongly	Moderately	Slightly	Not at all	Total	Yes	No	Total	Yes	No	Total	Yes	No	Total
Respondent characteristics (n = 180)	47.2	40	11.7	1.1	100	85.6	14.1	100	11.1	88.9	100	53.3	46.7	100
(1) Age														
6–15	40	40	20	NA	100	40	60	100	NA	100	100	60	40	100
16–30	45.6	40.1	13	1.4	100	85.7	14.3	100	10.9	89.1	100	53.1	46.9	100
31–45	71.4	29.6	NA	NA	100	92.9	7.1	100	7.1	92.9	100	57.1	43.9	100
46–60	41.7	50	9.3	NA	100	91.7	8.3	100	16.7	83.3	100	58.3	41.7	100
Above 60	50	50	NA	NA	100	100	NA	100	50	50	100	NA	100	100
(2) Sex														
Males	43.8	42.5	12.5	1.3	100	83.8	16.3	100	6.2	93.8	100	48.8	51.2	100
Females	50	38	11	1	100	87	13	100	15	85	100	57	43	100
(3) Level of education														
Educated at or below higher secondary level	31.3	37.5	25	6.3	100	68.8	31.3	100	18.7	81.3	100	43.8	56.2	100
Educated above higher secondary level	48.8	40.2	10.4	0.6	100	87.2	12.8	100	10.4	89.6	100	54.3	45.7	100
(4) Level of employment														

(continued)

Table 3 (continued)

Respondent characteristics	Level of concern about potential effects of HW on society and oneself					Experienced productivity loss during extremely hot days			Whether suffer from any chronic illness			Experienced extreme heat related symptoms/illness		
	Strongly	Moderately	Slightly	Not at all	Total	Yes	No	Total	Yes	No	Total	Yes	No	Total
Professional	67.6	29.4	2.9	NA	100	88.2	11.8	100	11.8	88.2	100	58.8	41.2	100
Salaried	41.3	45.7	13	NA	100	78.3	21.7	100	6.5	93.5	100	45.7	54.3	100
Homemaker	40	50	10	NA	100	90	10	100	20	80	100	40	60	100
Student	42.7	40.4	14.6	2.2	100	87.6	12.4	100	12.4	87.6	100	57.3	42.7	100
Retired	100	NA	NA	NA	100	100	NA	100	50	50	100	NA	100	100
(5) Annual household income														
<2,50,000	34.6	42.3	15.4	7.7	100	77	23	100	15.4	84.6	100	53.8	46.2	100
2,50,001–5,00,000	45	40	15	NA	100	92.5	7.5	100	10	90	100	52.5	47.5	100
5,00,001–10,00,000	52.7	34.5	12.7	NA	100	85.4	14.6	100	10.9	89.1	100	56.4	43.6	100
>10,00,000	49.2	44.1	6.8	NA	100	84.7	15.3	100	10.2	89.8	100	50.8	49.2	100

Source Primary Survey, April–June 2020; NA—Not Available

were either “slightly concerned” (11.7%) or “not at all concerned” (1.1%). Respondents across all the age groups appeared to be strongly concerned about the effects of HW, most being in age group 31–45 years (71.4%), followed by those in age group 16–30 years (45.6%). Only 1.4% respondents in age group 16–30 years were not at all concerned. Females (50%) were more strongly concerned than men (43.8%). Respondents, educated above HSL (48.8%) were more strongly concerned about HW effects than those below it. However, it can be seen that both were moderately concerned. About 6.3% respondents educated below HSL were not at all concerned. All retired people, mostly older in age, were strongly concerned about HW effects on their health, followed by professional (67.6%) respondents and students (42.7%). Respondents earning an annual household income between 5 and 10 lakhs (52.7%) were the most strongly concerned about HW effects, followed by those who earned above 10 lakhs (49.2%). About 7.7% respondents in income category of less than 2.5 lakhs were not at all concerned about HW effects on themselves and society in general.

Those respondents who were either “strongly or moderately concerned” (i.e., approx. 87.2% of the total respondents) about the effects heat waves may have on them personally or on the society were asked what they were concerned the most about during a HW event. Figure 3 shows that respondents indicated being concerned most about their health (83.9%) followed by birds, animals, and pets (67.2%); relatives/family/friends (46.1%), outdoor activities (42.8%), and personal comfort (39.4%). Other concerns included food and water contamination (38.9%), power cuts (32.2%), school closures (9.4%), and disruption to public transport system (7.2%).

Majority of the total respondents (85.6%) experienced a loss in productivity level during extremely hot days while 14.4% respondents did not feel any productivity loss (Table 3). Most respondents across all the age groups suffered productivity loss, with retired people on top, followed by those in age group 31–45 years (92.9%)

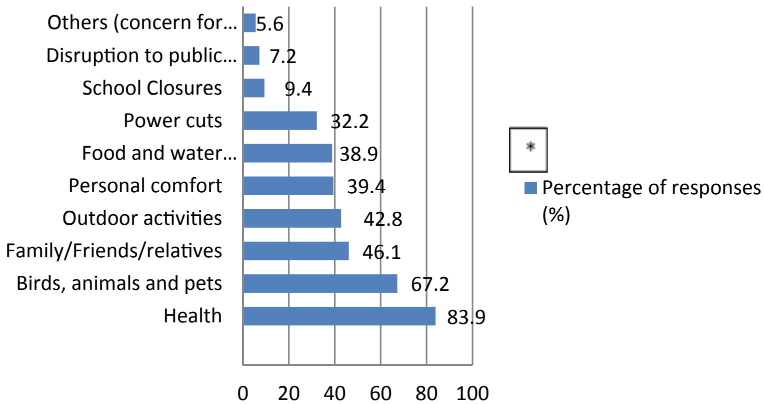

Fig. 3 Issues that are of concern to respondents during a heat wave. * % total may add up to more than 100% as multiple responses were permissible

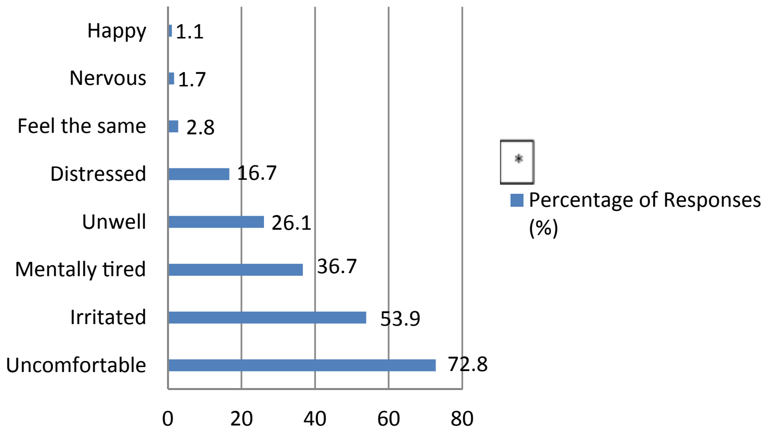

Fig. 4 Effects of heat waves on respondents' wellbeing. * % total may add up to more than 100% as multiple responses were permissible

and those in age group 46–60 years (91.7%). Most respondents in age category 6–15 years (60%) did not suffer any productivity loss, which shows young children are more active and resilient to HW impacts. Females (87%) experienced more productivity loss than males (83.8%). Respondents, educated above HSL (87.2%) experienced more productivity loss than those below it. About 31.3% respondents educated below HSL did not experience any productivity loss. All retired people, mostly older in age, followed by homemakers (90%), professionals (88.2%), and students (87.6%) experienced loss in productivity levels. Respondents earning an annual household income between 2.5 and 5 lakhs (92.5%) experienced loss in their productivity levels the most, followed by those who earned between 5 and 10 lakhs (85.4%). About 23% respondents in the income category of less than 2.5 lakhs did not experience productivity loss during HW event.

Respondents were asked about how they feel during periods of heat waves in Delhi. Figure 4 shows the most cited responses were feeling uncomfortable (72.8%), followed by irritated (53.9%), mentally tired (36.7%), unwell (26.1%), and distressed (16.7%). A proportion of 2.8% respondents felt the same/usual as on any other day. The least common cited response was feeling happy (1.1%) and feeling normal (1.7%).

Majority of the total respondents (88.9%) did not suffer from any chronic illness which is a good indicator since people with chronic illness are likely to be more vulnerable to the health impacts of heat waves. Only 11.1% of the total respondents agreed to be suffering from certain chronic illness. Most respondents across all the age groups did not suffer from any chronic illness. Only one retired person aged above 60 years suffered from chronic illness. About 16.7% respondents in age group 46–60 years, followed by 10.9% in 16–30 years age group suffered from some kind of chronic illness. More females (15%) than males (6.2%) suffered from chronic illness. Most respondents, whether educated above or below HSL did not suffer from any chronic illness. However, it can be observed that educated respondents below HSL (18.7%) suffered more from chronic illness than those above it. One retired person (50%), followed by homemakers (20%) and professionals (11.8%) suffered from some kind of chronic illness. Majority of respondents across all income groups did not suffer from any chronic illness. It can be seen from Table 3 that respondents earning an annual household income of less than 2.5 lakhs (15.4%) suffered from some kind of chronic illness, followed by those who earned between 5 and 10 lakhs (10.9%).

Majority of the total respondents (53.3%) have experienced some heat-related symptoms or illness at some point in their life, while 46.7% respondents have not. Heat exhaustion was the leading heat-related illness/symptoms experienced by respondents, followed by dry mouth/intense thirst and Heat Rash. From Table 3 it is clear that majority of the respondents across all the age groups experienced extreme heat-related symptoms/illness at some point in their life, with most of them being in age group 6–15 years (60%), followed by those in 46–60 years of age group (58.3%). No respondent above 60 years of age has experienced any heat-related illness/symptoms. About 46.9% respondents in age group 16–30 years have not experienced any heat-related illness/symptom. More Females (54.3%) have experienced heat-related illness/symptoms than males (48.8%). Most respondents, either below or above HSL did not experience any heat-related illness/symptoms. However, it can be observed that respondents educated above HSL (54.3%) have experienced more heat-related illness/symptoms than those educated below it. About 58.8% professionals have experienced heat-related illness/symptoms, followed by students (57.3%) and salaried (45.7%) respondents. Majority of homemakers (60%) and all retired respondents have not experienced any heat-related illness/symptom. Respondents belonging to annual household income category between 5 and 10 lakhs (56.4%) experienced heat-related illness/symptoms the most, followed by those who earned less than 2.5 lakhs (53.8%) and those between 2.5 and 5 lakhs (52.5%). About 49.2% respondents earning above 10 lakhs have not experienced any heat-related illness/symptom, followed by those belonging to 2.5–5 lakhs income category (47.5%).

Respondents who agreed to have experienced heat-related symptoms or illness were asked what kind of symptoms or illness they suffered from. Figure 5 indicates that Heat exhaustion (heavy sweating, weakness) (66.3%) was the leading heat-related illness/symptoms experienced by respondents, followed by dry mouth/intense thirst (49.5%), Heat Rash (44.6%). Food poisoning (12.9%) due to contaminated food was also experienced by the respondents. A proportion of 8.9% people suffered from Heat syncope (fainting or fell-down or go senseless because of excessive heat). It was also observed that Heat Rash (7.9%) (an irritation of the skin that results from excessive sweating during hot and humid weather. It can be small blisters or pimples) and Heat Cramps (7.9%) (any painful involuntary brief muscle cramps, spasm or jerk due to heat) were also experienced by the respondents.

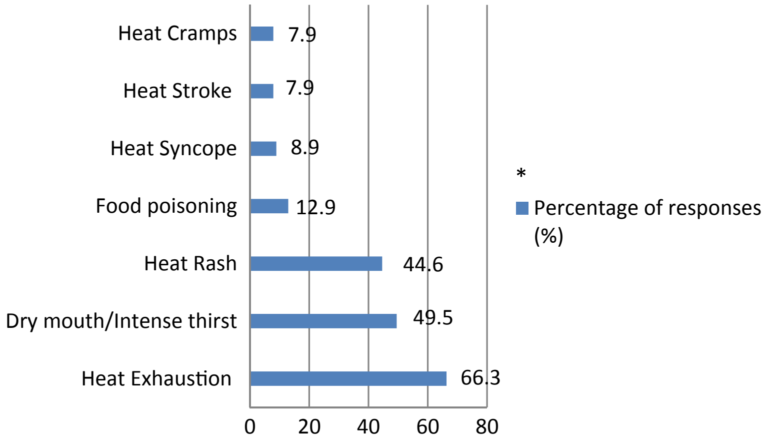

Fig. 5 Kind of heat related symptoms/illness experienced by respondents. * % total may add up to more than 100% as multiple responses were permissible

4.4 Coping Strategies Adopted by Respondent Characteristics

Respondents were asked a set of questions to understand the kind of coping practices and strategies they adopted at home and while going out to protect themselves from harmful impacts of HW. They were asked whether they visited a doctor or opted for self-medication if diagnosed with any heat-related illness or showed symptoms. From Table 4, it can be observed that the majority of total respondents (43.9%) neither visited the doctor nor opted for self-medication in case they were diagnosed with any heat-related illness or showed symptoms. About 41.1% of total respondents opted for self-medication while visiting the doctor was the least cited option among respondents (15%). Most respondents who visited a doctor belonged to age group 46–60 years (25%), followed by those in age group 31–45 years (21.4%) and 6–15 years (20%). Half of respondents (50%) aged above 60 years opted for self-medication followed by those in age group 31–45 years (42.9%) and in age group 16–30 years (42.2%). Majority of respondents in age group 6–15 years (80%) neither visited a doctor nor opted for self-medication if diagnosed with extreme heat-related symptoms, followed by those aged above 60 years (50%) and those belonging to age group 16–30 years (44.2%). Majority of females (46%) opted for self-medication while most males (88%) chose none of them. Females (19%) were more likely to visit a doctor than males (10%). Respondents educated above HSL (15.9%) chose to visit a doctor more than those below that it. Majority of respondents below HSL (88%) neither visited a doctor nor opted for self-medication if diagnosed with extreme heat-related symptoms. About 44.5% respondents above HSL opted for self-medication. Majority respondents across all the employment levels chose to neither visit a doctor nor opt for self-medication if diagnosed with extreme heat-related symptoms, with

Table 4 Coping strategies by respondent characteristics

Respondent characteristics	What people did if diagnosed with heat-related symptoms?				Intend to take sun stroke prevention measures				
	Visited a doctor	Self medication	None of them	Total	Strongly	Moderately	Slightly	Not at all	Total
Total respondents (n = 180)	15	41.1	43.9	100	37.2	38.9	16.1	7.8	100
(1) Age									
6–15	20	NA	80	100	40	20	NA	40	100
16–30	13.6	42.2	44.2	100	36.1	39.5	17.7	6.8	100
31–45	21.4	42.9	35.7	100	42.9	42.9	14.3	NA	100
46–60	25	41.7	33.3	100	41.7	41.7	8.3	8.3	100
Above 60	NA	50	50	100	50	NA	NA	50	100
(2) Sex									
Males	10	35	55	100	26.3	41.3	22.5	10	100
Females	19	46	35	100	46	37	11	6	100
(3) Level of education									
Educated at or below higher secondary level	6	6	88	100	37.5	25	NA	37.5	100
Educated above higher secondary level	15.9	44.5	39.6	100	37.2	40.2	17.7	4.9	100
(4) Level of employment									
Professional	14.7	41.2	44.1	100	38.2	47.1	11.8	2.9	100
Salaried	10.9	43.5	45.6	100	37	41.3	17.4	4.3	100
Homemaker	40	30	30	100	40	40	10	10	100
Student	14.6	40.4	45	100	36	34.8	18	11.2	100
Retired	NA	100	NA	100	100	NA	NA	NA	100

(continued)

Table 4 (continued)

Respondent characteristics	What people did if diagnosed with heat-related symptoms?				Intend to take sun stroke prevention measures				
	Visited a doctor	Self medication	None of them	Total	Strongly	Moderately	Slightly	Not at all	Total
(5) Annual household income									
<2,50,000	23	30.8	46.2	100	30.8	46.2	11.5	11.5	100
2,50,001–5,00,000	17.5	42.5	40	100	42.5	40	12.5	5	100
5,00,001–10,00,000	12.7	47.3	40	100	34.5	43.6	18.2	3.6	100
>10,00,000	11.9	39	49.1	100	39	30.5	18.6	11.9	100

Source Primary Survey, April–June 2020; NA—Not Available

salaried respondents (45.6%) being on top, followed by students (45%) and professional (44.1%). Majority of homemakers (40%) chose to visit a doctor if diagnosed with extreme heat-related symptoms, followed by professional (14.7%) respondents and students (14.6%). Among the respondents who opted for self-medication were those aged above 60 years (100%) opting the most, followed by salaried (43.5%) and professional (41.2%) respondents. Majority of respondents across all the income groups chose to neither visit a doctor nor opt for self-medication if diagnosed with extreme heat-related symptom, with most of them in income group of above 10 lakhs (49.1%), followed by those belonging to income group of less than 2.5 lakhs (46.2%). About 47.3% respondents in income group 5–10 lakhs opted for self-medication followed by those in 2.5–5 lakhs (42.5%). About 23% of respondents in income group of less than 2.5 lakhs chose to visit a doctor, followed by 17.5% in income group of 2.5–5 lakhs.

Respondents were asked whether they intend to take any sunstroke prevention measure when going out or when a high temperature warning is released or not. It can be observed from Table 4 that majority of the respondents (38.9%) were moderately intended to take some sunstroke prevention measures, followed by those (37.2%) who strongly intended to take those measures. Rest of the respondents were either slightly intended (16.1%) and 1.1% had no intention at all to take any sunstroke prevention measure when going out or when a high temperature warning is released. Majority of respondents across all age groups had strong intention to take sun stroke prevention measures, with half of those aged above 60 (50%) being on top, followed by those in 31–45 years of age group (42.9%) and in 46–60 years age group (41.7%). Half of respondents aged above (50%) did not take any sun stroke prevention measures at all, followed by those in age group 6–15 years. Males (41.3%) had moderate intention to take sun stroke prevention measures while females (46%) had more stronger intention. About 10% males and 6% females had no intention to take sun stroke prevention measures. Respondents educated above HSL (40.2%) had moderate intention to take sun stroke prevention measures while those below HSL (37.5%) had more stronger intention. About 37.5% respondents educated below HSL and 4.9% respondents educated above HSL had no intention to take sun stroke prevention measures. Majority of respondents across all the employment levels had moderate intention to take sunstroke prevention measures, with professional (47.1%) respondents being on top, followed by salaried respondents (41.3%) and homemakers (40%). All the retired respondents strongly intended to take sunstroke prevention measures, followed by homemakers (40%) and professional (38.2%) respondents. About 11.2% students had no intention to take sunstroke prevention measures at all, followed by homemakers (10%).

Majority of respondents across all the income groups had moderate intention to take sunstroke prevention measures, with those in income group of less than 2.5 lakhs (46.2%) being on top, followed by those in income group of 5–10 lakhs (43.6%). About 42.5% respondents in income group of 2.5–5 lakhs had strongly intended to take sunstroke prevention measures, followed by those earning above 10 lakhs (39%). About 11.9% respondents earning above 10 lakhs had no intention to take sunstroke prevention measures, followed by those in income group of less than 2.5 lakhs (11.5%).

Respondents were asked what kind of preventive measure they took when going out on an extremely hot day. Results are illustrated in Fig. 6. Among the preventive measures taken, most of the respondents (88.9%) carried water bottles and drank sufficient water, followed by choosing to avoid going out as far as possible (62.8%) and wearing light colored, loose, cotton clothes (62.2%). A proportion of 48.3% respondents covered their heads with scarf/cap/stole while going out, while 45.6% carried an umbrella. Another 41.7% chose to wear UV protection sunglasses and 40.6% avoided eating outside. 30.6% respondents had some cool beverages while going out on an extremely hot day. 25% respondents were in favor of never leaving children and pets alone and unattended during extremely hot days as they are at high risk from heat waves.

Respondents were asked what kind of coping practices they adopted at home to get protection from extreme heat during summers. Results obtained are illustrated in Fig. 7. Top coping practices adopted to get protection from extreme heat during summers included using fan/AC/cooler (90.6%); drinking enough water, even if not feeling thirsty (73.9%), wearing light, loose, and cotton clothes (72.2%). A proportion of 57.2% respondents chose to implement traditional strategies like having home-made shikanji, buttermilk, eating onions, etc. 32.8% respondents keep indoor green plants to keep their house cool. 25% respondents consider visiting green spaces like parks, gardens, etc. as a coping strategy to get respite from heat. 44.4% respondents use clay pot for drinking water, while 12.8% respondents cool their roof by painting them white. 57.2% respondents use curtains, shutters, and sunshades during daytime. 43.3% respondents open their windows at night to maintain adequate ventilation as a coping strategy.

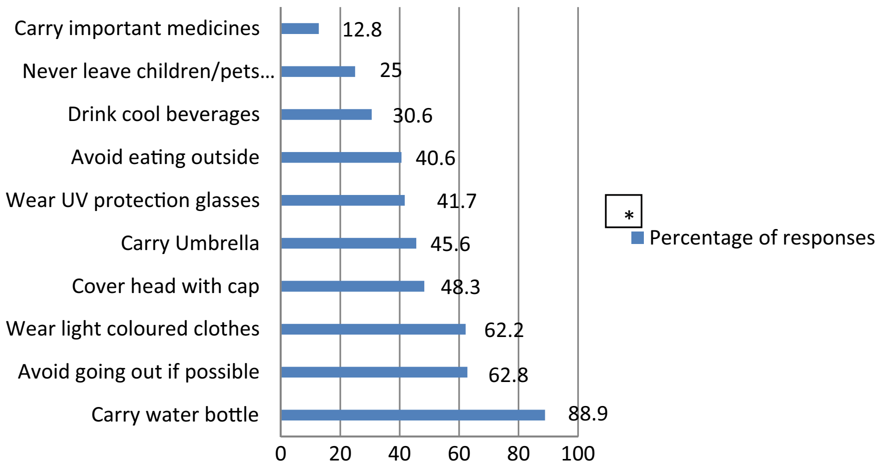

Fig. 6 Preventive measures taken by respondents when going out (%). * % total may add up to more than 100% as multiple responses were permissible

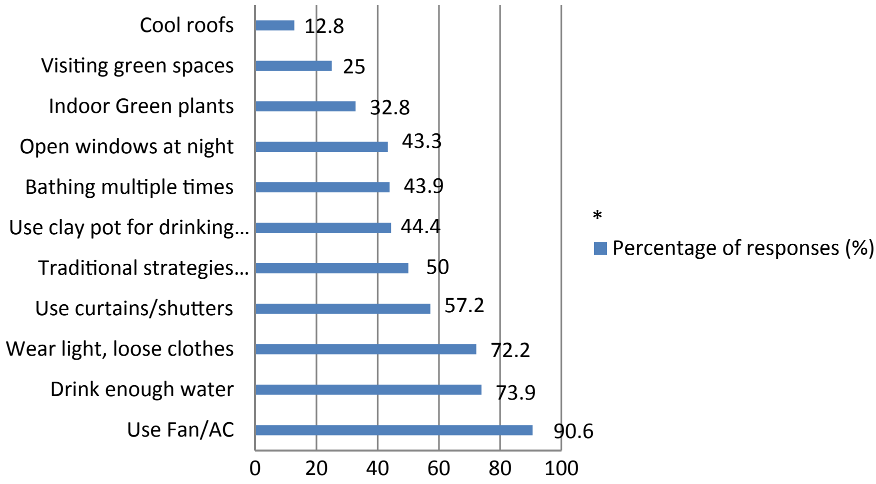

Fig. 7 Coping practices adopted by respondents at home against extreme heat. * % total may add up to more than 100% as multiple responses were permissible

5 Conclusion

Unprecedented heat waves have been recorded in Delhi over recent years, with 2019 being the warmest year on record. Extreme heat is a serious public health concern. A cross-sectional study was conducted during April–May 2020 among a sample of 180 residents of Delhi with the aim to assess how the public perceived the phenomena of heat waves and to understand the awareness of and attitudes toward heat waves and associated health risk and the coping practices adopted.

The results of this survey suggest that a majority of the respondents considered heat waves a disaster and extreme heat a serious public health risk and hazard. People in the city have experienced accounts of heat waves in the past and are well informed about them. The main source from which respondents obtained information about heat waves was Internet/social media. This finding shows the significant role that the social media plays in circulating information to the public. Some respondents were found to be concerned over certain issues during a heat wave, with health being the top most concern for a majority of them. Due to heat waves, certain groups in the community have been affected with emotional and psychological distress. Majority of the respondents felt uncomfortable during a heat wave event. Most of the respondents experienced a loss in productivity level during extremely hot days. Respondents with chronic illness are at a higher risk of being impacted by heat waves. Majority of the respondents have also experienced some kind of extreme heat-related symptoms or illness, among which Heat exhaustion was the top most symptom/illness. Most respondents opted for self-medication instead of visiting a doctor in case they were diagnosed with some kind of heat-related symptoms/illness. Among the preventive measures taken when going out on an extremely hot day, most people carried water bottles and chose to wear light colored clothes. Top coping practices adopted to get protection from extreme heat during summers included using fan/AC/cooler and drinking enough water.

It has been predicted by various scientists that across the planet, the average temperature during the summer is going to rise over the years. Hence, extreme heat days are inevitable in the future. These important findings may help the experts and policymakers to inform, reframe, and communicate strategies for tackling the problem of heat waves in the capital city and help people be better prepared in the event of heat waves. Since any victory to address potential consequences associated with heat waves may depend on views of the general public about the phenomenon, it becomes very important to have a thorough understanding of the public attitudes, awareness, and perception regarding heat waves.

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Resilience

Community-Based Flood Preparedness: A Case Study of Adayar Watershed, Chennai City, Tamil Nadu, India

O. M. Murali and S. Rani Senthamarai

Abstract This research work was carried out at six sites located along the banks of the Adayar River, Chennai city in India. The objective was to understand the relationship between community preparedness and response to seasonal river flooding. Community participation plays an important role and is an integrated component of flood management. Therefore, community involvement becomes fundamental and essential in flood preparedness. They seek to maximize the benefits through the related development activities within the river basin or watershed as a whole, and the benefits are derived at various levels of socio-economic activities through development policy and land-use planning. As the community comprises of various sub-groups as in the case of the study area (Urban Poor to higher income), its activities contribute to coordinating their interests and maximizing the benefits through building consensus within the community. The extent of community participation was based on the community's past experience and traditional backgrounds. However, the starting point in any Community-Based Flood Preparedness (CBFP) study is the understanding of the vision for the river basin or watershed as a whole. One of the important analyses in this research was the household as a social entity around which communities interact and respond together with their acquired skills to overcome flood impacts. One of the strengths of this research was to identify and review household perceptions on the flood, their coping strategies, and preparedness at case study locations. Participatory tools were used in this research to appraise the site and situation analysis through transect surveys, participatory or community mapping (participatory mapping techniques), seasonal calendar, and SWOT analysis. Each technique helped to understand ground reality, people's perception of their neighbourhood, exposure to floods, coping strategies in practice, the vulnerability of age groups, support from external sources at times of emergency, and preparedness to flood vulnerability.

Keywords Community mapping · Preparedness · River basin · Vulnerability

O. M. Murali (✉) · S. R. Senthamarai
Geography Department, Presidency College, Chennai 600 005, India
e-mail: om.murali@gmail.com

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1 Introduction

To understand the community vulnerability, reconnaissance survey was carried out at selected six locations (Figs. 1 and 2) along the Adayar river banks as case studies for the following reasons. These locations have been experiencing frequent flooding in the past years, and secondly, the problem of flooding was growing over the years. Thirdly, conflicts of interest between flood control measures and urban development in the settlement had been widely reported in mass media (television, radio, and newspapers).

Finally, the case study settlements have not previously been widely documented. Above all, the residents were proactive in taking measures to contain the flood situation. On the basis of the above criteria, the six locations were chosen as appropriate case studies for the present research.

A systematic transect of about 3,185 m along a defined path (transects) across each case study area together with the local people was conducted. Also, gathered information about the environmental condition as well about the community perceptions on various aspects using participatory tools such as Mind Mapping and Seasonal calendar. The researcher used Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis as a preliminary decision-making tool. A household survey with a structured questionnaire was also carried out among these communities, and the results of the survey were elaborated subsequently.

Fig. 1 Location of Adayar river in Tamil Nadu

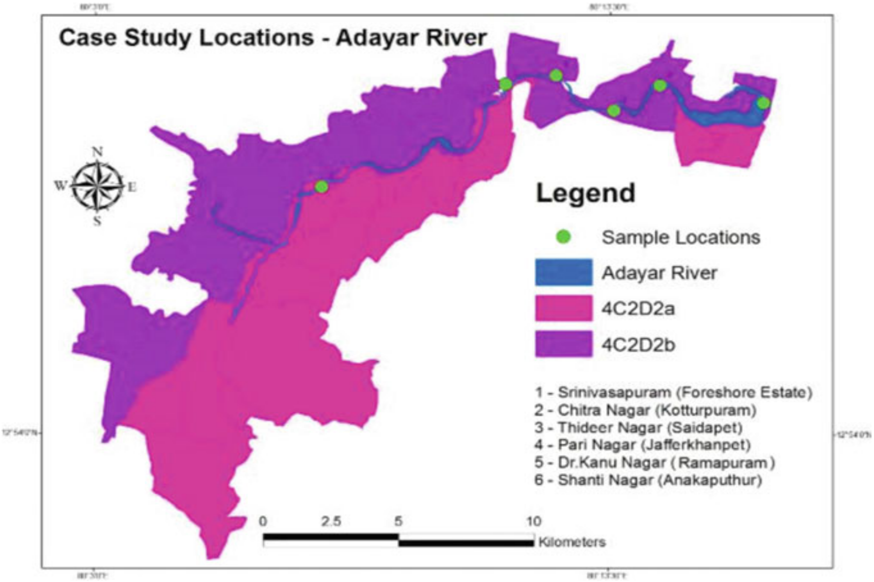

Fig. 2 Case study locations

2 Research Methodology and Analysis

As this research involves the community's readiness to recurring floods, it is essential to identify and review household perceptions on the flood, their coping strategies, and preparedness at case study locations. Further, participatory tools were used to appraise the site and situation analysis through transect surveys, participatory or community mapping (participatory mapping techniques), seasonal calendar, and SWOT analysis. Each technique helped to understand ground reality, people's perception of their neighbourhood, exposure to floods, coping strategies in practice, the vulnerability of age groups, support from external sources at times of emergency, and preparedness to flood vulnerability.

2.1 Site and Situation Analysis

The two of the most important concepts in the study of urban geography are **site** and its **situation** of the human settlement. **Site** is nothing but the actual location of a human settlement on the earth's surface and is composed of the physical characteristics of the landscape specific to the area which may include things like landforms (physical barriers like mountains or coastal), its prevailing climatic condition, natural vegetation, presence of water, and wildlife. **Situation**, on the other hand, is defined as the location of a place relative to its surroundings and other places. Factors included

Table 1 Site and situation of case study communities Adayar watershed, Chennai metropolitan area

Sl. No	Case studies	Site			Situation		
		Adayar river	Distance		Distance		
	Name of the settlement	Side of the bank	From sea (km)	From river (m)	Main road (m)	Daily needs (m)	Relief shelter (km)
1	Srinivasapuram	Eastern	On the sea shore	50	300	400	1
2	Chitra Nagar	Southern	4.5	70	50	200	2
3	Thideer Nagar and Attru nagar	Northern and southern	6	50	200	300	1
	Arokia Madha Nagar						
4	Pari Nagar	Northern	8	50	100	300	2
5	Dr. Kanu Nagar	Northern	10	70	600	700	2
6	Shanthi Nagar	Eastern	17.5	60	300	400	1

Source Compiled by Authors

in an area's situation include its accessibility, connectivity with another location, and how close an area may be to other essential materials which serve the community to flourish well on the site and grow.

In this study, site and situation of the case studies (Table 1) play an important role in determining the extent of the challenge posed to the communities by the frequency of inundation during monsoon rains, cyclonic storms, and unusual events like Tsunami.

2.2 *Case Study 1 Srinivasapuram*

Srinivasapuram settlement is a fishing hamlet situated on the shores of the Bay of Bengal and is bounded by water on its three sides. Srinivasapuram was severely impacted by the 2004 Indian Ocean Tsunami. According to a report, there are currently 2,682 tenements and 7,000 encroachments in Srinivasapuram, Foreshore Estate area. Srinivasapuram is also nicknamed as "*Little India*", because people from North India settled here for their livelihoods. The Chennai Master Plan II identifies Srinivasapuram as a "Residential" zone.

Transact Survey

The transect line measuring 495 m along the Srinivasapuram was carried out by the researcher with the help of local persons (Fig. 3).

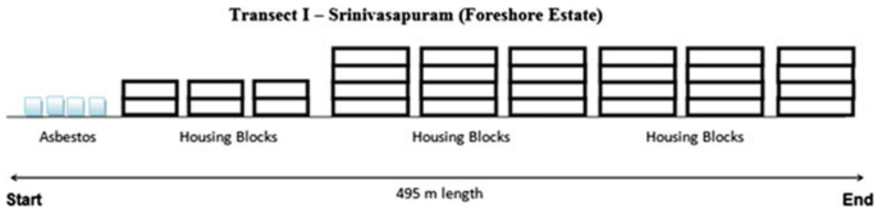

Fig. 3 Transect path at Srinivasapuram, Foreshore estate

Key Findings: High density of population resulted in garbage accumulation. Sewage drainage block and leakage were observed at many places. The garbage accumulation is widespread on the beachside (eastern side), where the urban poor resides. There was no proper sewage system and no toilet facility; hence, this part of the beach is highly polluted with solid waste and open defecation.

The Memories of Indian Ocean tsunami December 2004 as narrated by the Local People

The memories of the Indian Ocean Tsunami 2004 are still fresh in the minds of the residents in the community, which swept away everything in seconds even before people could think and act. They were able to quickly recollect their neighbourhood and could say the direction and the extent of tidal waves during the tsunami impact.

In this locality, nearly hundreds of people were swept away by the tsunami. An aged person narrated the event as "This was the first ever tsunami the entire community faced and even before they could think of why the sea water withdrew, but it came back with a 'wall of water' and swept everything away. He also added that it was in the morning of Sunday in 2004 when the people were still to resume their daily work and many of them were still in the bed to enjoy the extended sleep in the holy weekend.

It was never imagined that the sea would punish them with such severe force where a couple of their neighbours were swept away. The first wave came at around 8.30 am and, later on, it was followed by secondary waves which came after half an hour. The force of the tidal wave was so powerful that it deposited huge piles of sand in their houses and caused extensive and irreparable damage to lives and property. Later on, they were quickly accommodated in the shelters for the next few days to a week, in fact until further notice from the Government for the safety of the houses for possession. Apart from staying in the shelter, many people opted to stay with their relatives".

Damage and loss were unimaginable, especially of the loved ones where close to 90 people perished in the tidal wave. Property damage was total and unlike the gradual rise of floodwaters; it happened so quick, without a warning and nothing could be prepared by the community. Property damage was in excess of Rs. 100,000 to Rs. 500,000. Very fine sand had penetrated everything in their houses: television, refrigerator, computer, vehicle engine, water tank, sewage pipe, bureau, and washing machine. Nothing could be used again and gone out of operation. The tsunami was a lesson not only to our community but to the entire world.

2.3 The Case Study II: Chitra Nagar

The Chitra Nagar is located on the southern bank of Adayar River, where the river meanders. From reliable sources, it has 23 blocks and 460 houses. Among the case study locations, this settlement was the worst affected by the 2005 and 2015 floods. The memories of flood experiences were fresh in the minds of the people.

A transect walk of about 1,075 m around and across the settlement was undertaken by the researcher along with Mr. Selvam, the resident of the area. The information gathered during the visit indicated clearly that the communities lived in close relationships with one another, which was the key element of any successful neighbourhood in a flood-prone area. Participants were aware of their localities for high elevation (safe places during the flood inundation) and low-lying areas (to avoid during the floods).

Transect Survey

The 1,075 m transect path was started and conducted in four parts across the settlement.

Part 1 (200 m transects)—This transect remained relatively free from human settlement, and during the rainy season, this part of the settlement acted as a water sink through which the rainwater percolates and minimizes the flooding nearby.

Part 2 (200 m)—This stretch is well protected naturally by bushes, and trees covered the path which acts as a natural barrier to protect the community from river flooding.

Part 3 (200 m)—This transect passes through built-up named as 'R block'. It is a densely populated block running in north-south direction and on both sides of the transect, making it more dense and congested of all transects completed. During 2005 and 2015 rainfall, the entire stretch was inundated, making it difficult for people living on the ground floor, and they were forced to leave their houses and stay on the first floor, as revealed by one of the occupants (Fig. 4).

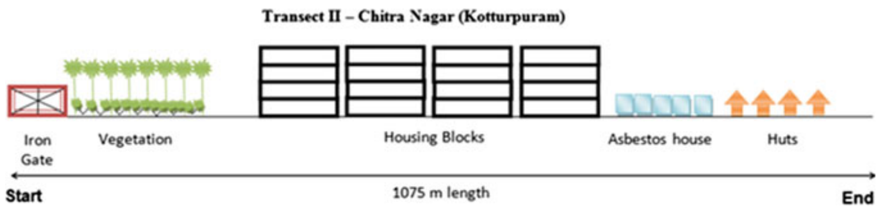

Fig. 4 Transect path @ Chitra Nagar, Kotturpuram

Part 4 (475 m)—This stretch covered parts of huts close to the river on the northern side.

Key Findings: Another high-density populated area located on the raised bank of the Adayar River. Slum clearance board houses dominate this locality with huts and encroachment towards the river bank with open defecation, and garbage dumping was prevalent on the river bank. During 2005 and 2015, this locality was severely flooded completely drowning the houses on the ground floor.

2.4 The Case Study III: Thideer Nagar

Aatru Nagar and Thideer Nagar are part of Saidapet slums found along the Adayar River. These settlements are situated on the northern and southern banks of the river, 6 km away from the sea. As a flood mitigation measure, a 10 ft concrete wall was erected on the northern bank of the river to protect the population from flooding from the river. The floods of 1985, 1996, 2005, 2008, and the recent 2015 were fresh in people's memories.

The researcher's frequent visits helped to befriend Mr. Kalidas who resides in this locality along with Ms. Kaliamma, Mr. Marimuthu, Ms. Rukmani, and Mr. Senthilnathan during the transect walk. The information gathered during the visit indicates clearly that the community lives in close relationship with one another, which is the key element of any successful living where people are exposed to frequent flooding. This openness of the community, in spite of having primary education, understands well the local geography (terrain of Saidapet). These are the key factors that help them escape any disaster situation without any major loss of the lives and property.

As they grew up here, their local knowledge is extremely good where they are even able to recollect key points of interest (POI) like locations of the temple, medical shop, vegetable shop, water pipes, water tanks, accumulated garbage, open latrines, and meat shop. Above all, they understand areas of higher elevation (safe places during flood inundation) and low-lying areas (places to avoid during the flood). This group is living from across the locations like Thideer Nagar and Aatru Nagar. A community living along the transect area is better prepared and possesses rich geographic knowledge about their environment.

Transect Survey

Here, the transect was carried out in three stages covering 550 m.

Stage 1—The first stretch lies on the river bed itself. Along the length of the stretch, grass and bushes were noticed and a few children were following curiously to know what was going on. Most of this stretch had human droppings and it was an indication that the communities living in this stretch do not have latrine facility.

Along the transect, seventy-year-old man was drying the cloth, and during the interaction, it was learnt that he was doing dhobi work for over 40 years in this location. He has been very happy with his profession and has seen over dozen floods

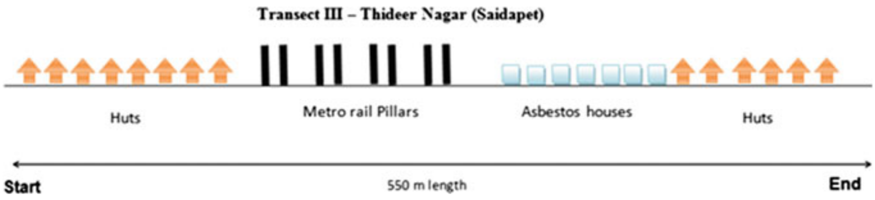

Fig. 5 Transect path @ Thideer Nagar, Saidapet

in this location. He was able to tell the occurrence of rainfall (season), the rise of floodwater, the height and extent of historic floods, support extended during flood situations, and the post-disaster preparedness to run the family (Fig. 5).

Stage 2—Second transect was carried out from north to south running parallel to the bridge. Lots of activities were observed during the fieldwork. From the adjacent Grand Southern Trunk road near the bridge, this location is 15 ft down. Piped water is supplied through metro water and children and women were actively engaged in taking baths and washing their clothes. Underneath the bridge, dozens of cattle were tied and were part of their permanent residence though the stretch was badly polluted. On the eastern side of the transect, nearly hundreds of huts were found.

Stage 3—The last stretch of the transect was most densely populated. It was located on the western side of the bridge and located towards the river bed. This locality was known as Thideer Nagar. Here, we could notice single-room houses. Each house measured 10 × 15 m with an asphalt rooftop. Concrete roads were laid with stormwater drainage to clear the excess water. Piped water supply was erected at strategic locations to cater to the drinking water supply of the community. Towards the riverside, the environmental condition was very bad as most of the garbage dumping took place which was never cleared.

Key Findings: This transect consists of only economically poor sections of the community and they were literally living on the riverbank in huts. Before the release of water, the entire community will be shifted to nearby school, church, and marriage halls. People will come back to their houses after a week or so depending on the extent of the flooding.

2.5 The Case Study IV: Pari Nagar

Pari Nagar is located in Jafferkhanpet, the settlement is situated on the northern bank of the Adayar river, and the elevation with reference to the river is near equal. Hence, a 10 ft concrete wall was raised on the northern bank of the river to protect the population during flooding. This stretch is located immediately adjacent to the Adayar River. This was one of the worst affected localities in the 2005 and 2015 floods.

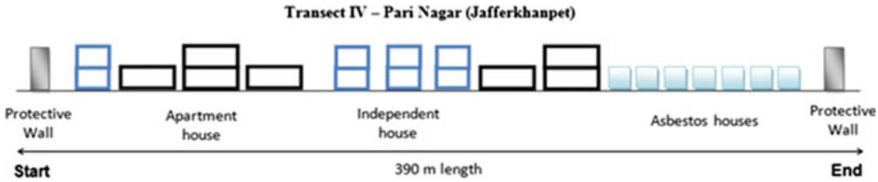

Fig. 6 Transect path @ Pari Nagar, Jafferkhanpet

During the transect, Mr. Mani, Mr. Xavier, Ms. Karpagam, and Govindammal had been very cooperative to share their experiences of living in this location for decades.

Transect Survey

For the entire length of the transect of about 390 m, it was observed to have around 300 houses. Though the locality was protected by a strong wall, it was a low-lying area, and excess water released from Chembarambakkam Lake could flood immediately with the rise in water level. Depending on the seasonal rainfall and the number of cyclones, the extent of the flood could be more. To their memory, the record rainfall and subsequent flood were severe in 2005 and 2015 as revealed by the community. The water depth was considerable for a day and the entire ground floor was flooded completely damaging the household properties. The worst case was in 2015 when the rapid rise in water level resulted in a few deaths in this stretch (Fig. 6).

Key Findings

Power cut was extended for a few days and the entire locality was in dark in 2005 and in 2015. The water level well reached the first floor. In some houses, especially women and a few people had locked their houses and stayed with their relatives and in shelters arranged by the local government. A further walk along the transect helped to notice a cavity created at the bottom of the wall at a few locations. It acted in both ways, excess floodwater from the Pari Nagar was naturally let into the river through a gradient, and on the other side, excess water from the Adayar River could enter the community as well during monsoon season.

Prior to the actual flood situation, the community was informed of the release of water from Chembarambakkam and advised to leave the place or temporarily accommodate in the nearest shelter. During flood times, the worst thing faced by them was the post-flood clean-up efforts. Human excreta were the single most challenges faced by the community to clean from their houses. Occasionally, they were experiencing the insects and snakes which emerge and get carried away by the floodwater. This clean-up required huge efforts, and after removal, they paint the house without which it would look ugly. This way, the expenditure for clean-up alone would go to over Rs. 10,000 during a severe flood situation, as revealed by the resident.

2.6 The Case Study V: Dr. Kanu Nagar

It is located at Ramapuram. It is a residential area located on the northern bank of the Adayar river. The settlement is 10 km away from the sea and a few metres from the river but almost at the same elevation. Dr. Kanu Nagar at Ramapuram was a combination of high- and low-income community settlements, located very close to the Adayar river. And the few communities live not more than 3 m away from the river.

This transect was accomplished with the extended support of Ms. Kanchana Rangan, Ms. Arasamma, and Mr. Balaraman. This stretch was very much away from the nearest bus stop (more than 1 km) and need a private vehicle to reach to this spot.

Transect Survey

Transect path covering 450 m was started at the entrance of the sub-station towards an easterly direction until the Adayar River (Fig. 7).

Key Findings

Part of the location is near the level of the river bed and this result in ground floor flooding in areas located near Dr. Vimala Convent Matriculation School and Amirtha Vidyala. During the transect walk, I interacted with Dr. Vimala Convent school neighbour, who revealed the flood water height during 2005 and 2015 rainfall. This area was completely cut off from the rest of the city and we remain trapped for over a day. It was an unprecedented rainfall coupled with untimely and unannounced water releases from Chembarambakkam Lake at one go resulting in complete inundation of this low-lying area.

These communities live not more than 3 m from the river. During the rainy season and before the release of water from Chembarambakkam Lake water, the police come regularly and give open announcements loudly to vacate the place before a specified time.

Perishable home items were kept safely near the roof to minimize the damage caused by floodwater. Secondly, communities either move to the shelter or stay for a few days in their relative's house away from their home. They keep the house locked and revisit the place every 3 or 4 h to analyse the situation. Depending upon

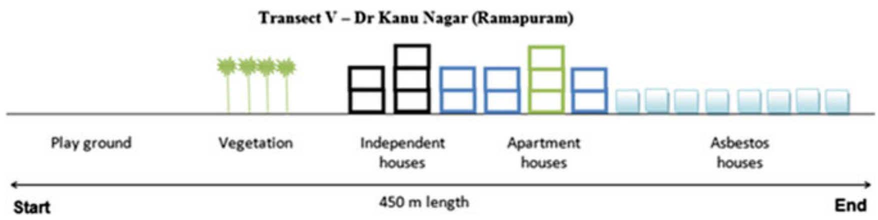

Fig. 7 Transect path @ Dr. Kanu Nagar, Ramapuram

the severity of the flood, they might remove some more vulnerable items to higher ground.

Post-flood clean-up remains the biggest challenge to the community living very close to the river. Also, insects and snakes pose a threat as they were swept away by the fast-moving water. Garbage pile-up, building debris, and construction on the river bank have reduced the river width and resulted in the flooding of houses.

3 The Case Study VI: Shanthi Nagar

Shanthi Nagar is situated outside Chennai Corporation limit but in Anakaputhur municipality of Chengalpattu District within the CMA boundary. It is situated within 5 kms from Chembarambakkam Lake, the prime source of floods in Adayar River. This settlement is situated on the eastern bank of river Adayar, and whenever surplus water is released from the Chembarambakkam Lake, the water reaches Thiruneermalai, where the Adayar river gains significant width to be designated as a river and continues downstream before being emptied into the Bay of Bengal. The flow would be considerable depending on the volume of water released and the rainfall in the upper catchments, and this formed a major source of flooding in the downstream of the Adayar river. Shanthi Nagar in Anakaputhur was particularly selected as it is located adjacent to the Adayar River and frequently faces flood havoc during monsoon seasons.

Transect Survey

The transect line covered Shanthi Nagar (a walk of 225 m), and a mixed low-income residential locality consisted of around two hundred houses. Out of this, close to fifty houses consisted of huts found on the river bank itself. Fortunately, the river bank was well raised to over 4 m and this protects the communities during flood season to some extent. Before reaching the transect path, the general topography drops down to the river bed where the entire stormwater drain connected sewage emptied into the river. Plastic was the dominant garbage, which forms part of the municipal wastes generated and found its way into the Adayar River through stormwater drainage (Fig. 8).

Key Findings: Along the stretch, houses were not having a proper drainage system, and a buried pipe was connected from the house directly to the river. The

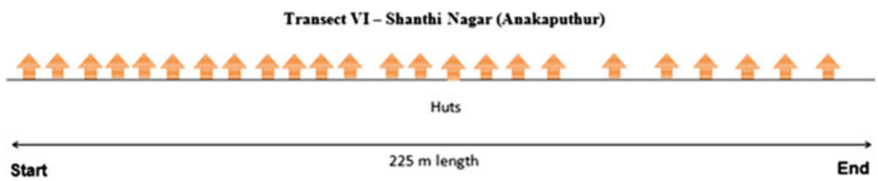

Fig. 8 Transect path @ Shanthi Nagar, Anakaputhur

municipal sewage was the main reason for pigs which freely roam and scavenge on the sewage wastes. Water found on the river was nothing but the sewage generated from the municipality which was dumped through the connected pipes and stormwater drainage. Additionally, nearby industries do dump untreated water into the river. The pig was the most commonly found scavenger in this part of the Adayar River. The communities were vulnerable to infectious diseases through contact with the pigs and buffalos (Photo Plate 1).

Local participants like Ms. Kannamma, Mr. Selvaraj, Ms. Chokkamma, and Mr. Raja helped to gather valuable information about the lives of the people in this locality. The community was well informed by the local government before the water release from Chembarambakkam Lake. They take shelter in the government school for a few

Photo Plate 1 Transect locations (Photos by Authors) days before water levels reduce in the Adayar River. Property damage was the most seen loss to the community, and on occasions, buffalos could get carried away by the force of floodwater. Community invariably used the toilet facility constructed at the northern end of the transect. Women used the facility provided and were spending Rs. 25/month. On the other hand, men preferred open defecation.

Soon after the release of water from Chembarambakkam Lake, within 1 h, water reach this spot, and longer the release, the flood situation continues longer and accordingly, communities opt out of the house and stay nearby depending on the extent of the flood. After the retreat of the flood, the flood relief amount of Rs. 2,000 would be distributed after the necessary verification of the ration card.

4 Participatory (Mind) Mapping

The next important technique is participatory mapping to understand the knowledge level of the community where mind mapping tools were used. Individuals comprising of children, men, women, and the elderly of the local area were involved in this exercise to prepare hand-drawn maps (sketches) of their immediate environment. This mapping technique was used to understand what could be important to individuals, routes they use frequently, knowledge level of the surroundings, and escape routes in times of flood. This helped greatly to know the vulnerable areas and population to prepare them for emergency situations. The mind mapping exercise (Fig. 9) across six locations yielded the following findings:

1. Women are not much familiar with their neighbourhood, except from their house to the main road where they do shopping. They know where the shops, especially, home needs shops, are located. Their perception of high ground and low land was not much evidenced. Also, in times of emergency situations, they tend to remain at home rather than move to relief centres or higher ground. Also, their contribution to the preparation was not very significant but mostly confined to the home.
2. Children have less perception of their environment, but are familiar with their nearby landmarks. But they are not much aware of highland, lowland, and escape routes. They depended upon their parents at home. Their perception level improved at the ages of around 7 and above.
3. Older people, due to their restricted mobility, memory loss, and existing health factor, have to depend on the younger members of the family. But their knowledge level is very good in sharing even minute details of the locality, historic floods, highland, and lowland, and they suggested ways to improve the neighbourhood.
4. Men are very knowledgeable of their immediate environment, areas of highland and lowland, location of shops, the extent of the historic flood, and escape routes.

Srinivasapuram, Foreshore Estate

Chitra Nagar, Kotturpuram

Thideer Nagar, Saidapet

Pari Nagar, Jafferkhanpet

Dr. Kanu Nagar, Ramapuram

Shanthi Nagar, Anakaputhur

Fig. 9 Mind mapping exercise by the local community

5 Seasonal Calendar

Another participatory mapping method used is the preparation of a seasonal calendar. This helps to explore and record data for distinct time periods such as months, seasons, or years to show cyclical changes in events over time. Seasonal calendars include a range of indicators to understand how different patterns of change are linked and give insights into the stress the community faces in disaster-related events. Common challenges across all locations are flood inundation. The important period is the northeast monsoon (October–November–December). During this time, all six locations experience monsoon rains coupled with cyclonic rainfall. Health issues follow the rainy season every year which stresses the community further due to poor living conditions and poverty. Fire is confined to the hot season, particularly April–May, when the study area experiences high temperatures, blowing hot air resulting in accidental fires, especially of huts. Fire is noticed in Saidapet slums and Srinivasapuram slums.

Land and water pollution is a year-round challenge and a serious concern across all six locations. Using the seasonal calendar as the tool, local authorities and communities can well prepare themselves ahead for the risk posed by natural calamity and reduces the loss and damage to a minimum (Table 2).

6 SWOT Analysis

The information gathered through the local residents and observations noted during the field visits were compiled for the six case study locations to identify the Strengths, Weaknesses, Opportunities, and Threats (SWOT). For this purpose, SWOT analysis was performed, setting out a series of conclusions which they seek to respond to different strategies. Strengths and weaknesses are internal factors considered in the Adayar watershed under study, while opportunities and threats are posed by external factors. The internal factors, strengths and weaknesses, give certain advantages or disadvantages of flood management in the watershed. On the other hand, the external analysis examines the opportunities and threats that exist independently of the watershed. The SWOT matrix for floodwater management in the study area is shown below:

Key strengths: • Local, regional, and national governments schemes in the flood management • Structural measures • Non-structural measures • State law enables local authorities to adopt floodplain regulations • Floodplain management standards in state building code • Low risk of flooding due to water controlled by check dams upstream • Connecting the majority of the population to a social network	Key weaknesses: • Strong seasonality in the annual rainfall volume and Flood risk caused by episodes of exceptionally heavy rain • Sedimentation in the majority of lakes and thus reducing the volume of water-carrying capacity • Lack of stormwater drain and clogging of sewerage network of the study area • High level of pollution and garbage dumping • High degree of encroachment of water bodies and the flood plain in the study area • No state policy for the protection of naturally functioning floodplain resources

(continued)

(continued)

Key threats:	Key opportunities:
• The sudden release of surplus water from reservoirs resulting from heavy rainfall in catchment areas associated with climate change • Flood periods during the monsoon months by processes associated with tropical cyclones • Significant increase in the built-up area due to rapid urbanization • Migration of rural population towards the city and high demand in the housing sector • Legislative trend towards pre-emptive regulations resulting in single entity authority without regard for floodplain management criteria	• Appropriate legislative framework for proper flood management • Implementation of the measures defined in the flood management framework directive • Compliance with environmental objectives • Promoting active participation of all stakeholders in the implementation of this directive • Interagency coordination (State Hazard Mitigation Team) • Capacity building through training and workshop prioritizing flood risk reduction for state-funded, licensed, and undertaken activities

7 General Profile of the Vulnerable Communities

As many as 498 respondents were selected from the six sample locations and they were interviewed with a custom-designed questionnaire. The respondents in each sample location are given below in Table 3.

To better understand the socio-economic and demographic setup of the communities living along the Adayar river is to understand the vulnerabilities of the communities, the coping strategies adopted, and the community's willingness to participate in flood risk mitigation.

7.1 Demographic Profile

1. **Age**: The respondent households represented all age groups, from less than 20 years to more than 75 years, although the youngest of the interviewed was 18 years old and the oldest 80 years. Nearly 68% of the interviewed belongs to the middle-aged, between 25 and 50 years. Another 25% of the population belongs to above 50 years of age. The remaining 7% falls below 25 years of age. A fairly large proportion of the population had shown significant perceptions about the dangers posed repeatedly by floods and their adaptations to the neighbourhood challenges.
2. **Occupation**: Occupation of individuals varied from daily wages to salaried persons. Close to 32% of the population belongs to daily workers where their sustenance depends on daily work. Salaried individuals cover 24% of the total population. The third highest occupation belongs to professionals who cover

Table 2 Seasonal calendar—sample locations

Vulnerability	Locations	January	February	March	April	May	June	July	August	September	October	November	December
River/cyclonic/flash flood/inundation	S1, K2, P3, T4, C5, S6				Cyclonic/flash flood/inundation					Cyclonic/flash flood/inundation			
Diarrhoea/water-borne diseases	S1, K2, P3, T4, C5, S6				Diarrhoea/water-borne diseases					Diarrhoea/water-borne diseases			
Land and water pollution	S1, K2, P3, T4, C5, S6	Land and water pollution											
Fire	T4 and S6				Fire								

Source Transect survey

Table 3 Share of respondents by select communities

Locations	Srinivasapuram	Chitra Nagar	Thideer Nagar	Pari Nagar	Dr. Kanu Nagar	Shanthi Nagar
Respondents number	71	70	157	67	68	65

Source Questionnaire survey

16% of the total workforce. The remaining covers 1–2% which covers business, fishing, and post-retirement employment.

3. **Education**: More than a fourth (27%) of the total respondents did not have formal education. A sizeable proportion of the people (10%) completed lower primary education (1–5 classes), while about 16% of them completed upper primary education (6–8 classes), 21% of them secondary school (9–10 classes), and 11% higher secondary school education (11–12 classes). Those with collegiate or university or technical or industrial education constituted 14%.
4. **Family size**: The respondents are reported to have small families (1–4 members; 85%) or medium families (5–6 members: 15%). There were families with one (2%), two (21%), three (36%), four (26%), five (14%), and six (1%) members.
5. **Household Assets and Losses**: Depending on the income and purchasing power of the households, assets varied drastically across the six locations. Major assets observed included television, refrigerators, air conditioners, furniture (chair, cot), two-wheelers (bike, bicycle), bureaus, computers, catamarans, and fishnets. Asset damages ranged from Rs. 1,000 to over Rs. 1,00,000.
6. **Relief and Rehabilitation Time and Expenditure**: Rehabilitation time varied from less than 1 h to over 24 h. For 8% of the flood-affected, it took 2 h for relief. For 40% of the respondents, it took between 3 and 5 h for rehabilitation from the flood-affected location to a nearby safer shelter. Whereas 49% of the population waited between 6 and 10 h before rehabilitation can take place. Expenditure and income loss during the rehabilitation phase ranged between Rs. 500 and Rs. 10,000 and 60% of the affected had expenditures less than Rs. 1,000. Expenditure between Rs. 1,000 and Rs. 5,000 was reported by 38% of the flood-affected households.
7. **Diseases and Healthcare**: Due to unhygienic living conditions and water stagnation mixed with open drainage, diarrhoea accounted for 37% of the affected population. General fever accounted for 28% during the rainy season with cases of malaria registered among 2% of the population. Persons injured during flooding time, rescue, and relief accounted for 12% of the population. Respiratory diseases accounted for 12% of the population and insect bites, particularly during flood time, accounted for 8% of the population.
8. **Medical expenses**: During floods, almost 88% of the population spent an average of Rs. 1,000 for various ailments. Medical expenses ranged between Rs. 1,000 and Rs. 2,000, for 8% of the population. Less than 1% of the population spent more than Rs. 2,000. Medical expenses for various illnesses ranged from Rs. 200 to Rs. 3,000, across the study area.

8 Socio-economics and Infrastructures

From the socio-economic status, family income ranged from as low as Rs. 5,000 to over Rs. 50,000. As much as 26% of the people of the six communities earned below Rs. 5,000 per month, which indicated the indirect vulnerability of the family members as well. About 33% of the households fell into the category of Rs. 6,000 and Rs. 10,000. This was close to 50% of the population, which earned below Rs. 10,000 per month. About 9% earned between Rs. 11,000 and Rs. 15,000. As for above Rs. 15,000, only 7% of the people of the communities were under this category. Nearly 24% of people did not disclose their income.

Close to 54% of the population lived in houses having a size less than 250 sq. ft. 14% lived in houses having sizes between 250 sq. ft. and 500 sq. ft. Only 2% of the population lived in housing with sizes above 500–750 sq. ft. This showed that the economically weaker sections were with marginal infrastructures made available to them. But, 29% of the population did not disclose the size of the houses.

9 Conclusion

This research study helped to understand the community's perception and preparedness towards seasonal flooding at six sites along the Adayar River in Chennai city. A reconnaissance survey was initially conducted accompanying the community members who had the best local knowledge of their areas. Other community-driven tools like transect survey, seasonal calendar, SWOT analysis, mind mapping, and river profile were prepared in participation with the local population of all age groups. This was the biggest success factor in getting the first-hand information on community perception, their preparedness, coping strategies for floods, and disaster resilience. Further, the questionnaire survey helped to know the living conditions of the population, their age structure, income, occupation, environmental stress, prevailing infrastructure, and the support they derive from governing bodies.

Their local knowledge is extremely good among the young generation who knew areas of vulnerable spots. On the other hand, children, women, and elderly people lack such knowledge making them vulnerable to floods as revealed through a mind mapping exercise.

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Building Resilience and Management of Vulnerability: Solution for Reduction of Risk of Disasters

Nizamuddin Khan and Syed Kausar Shamim

Abstract Disaster is a serious disruption to the functioning of a community that exceeds its capacity to cope with using its own resource. It is the outcome of the level of venerability and manageability or capacity, potentiality and ability to face and adopt the challenges or risk generated with the disasters. Disaster management is concerned with preparation, prevention, response and recovery functions in an affected area. The present paper is a form of descriptive research based on literature survey on disaster risk and its management as well religious text. The study aims to explore the process of building resilience and management of vulnerability and its effect on reduction of disaster risk in any area and time. Study reveals that the religious knowledge and statements are not capable to explain scientifically the genesis and warning of occurrence of hazards and disasters but provide a strong base to the scientists for further exploration. It is revealed from various literature that all kinds of disaster events have hidden scientific systems to be explored. The important components, i.e. preparedness, response, recovery and rehabilitation would be optimally and rationally managed with the motivation and persuasion of religious leaders, institutions and organizations in or out of disaster-affected areas along with the formal public and private agencies responsible for proper pre- and post-disaster management. It is further suggested that the society and community should be built disaster resilient from bottom to up and an integrated approach of local indigenous traditions, perception, rituals, religious education and government agencies as well as scientific opinion and measures must be adopted at the time of formulating strategy for disaster management to achieve sustainable development in affected region. Management of vulnerability is the key for disaster risk reduction management.

Keywords Disaster · Preparedness · Risk management · Sustainable development

N. Khan · S. K. Shamim (✉)
Department of Geography, Faculty of Science, A.M.U, Aligarh, India
e-mail: kausar55@gmail.com

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1 Introduction

Disasters bring out visible changes on surface of the earth through distraction to the operational activities. The resources of the area are all set to respond against the impacts of disasters by providing resilience. Disasters are multi-faceted phenomena caused by either nature or human beings revealed in different forms like earthquake, volcanic eruptions, floods, droughts, social crime, etc., and their intensity varies spatially according to the level of exposure and vulnerability of affected people. The impact of disasters depends on how the resources are organized and managed because the disasters are limitless and are not confined to any particular area irrespective of their origin; thus causes the destruction which eventually leads to exclusion from society (Mizutori 2020). Undoubtedly disasters act in such a way that one cannot separate it from other natural phenomena, so are studied in an integrated way with environment. Environment has got different spheres like lithosphere place where we live; atmosphere air which surrounds the earth; hydrosphere (including Cryosphere)-provides water; and finally, the Biosphere-which depends on other spheres to sustain life. The integrated approach to study the environment has been sought for in this era due to several reasons like the way of interaction in which biotic and abiotic communities are interacting to bring the changes in any region. The impact of disasters may not be quantified all the time but potential threat may be recognized through assessment of exposure and vulnerability as well as susceptibility. The earliest record of disasters reveals that hazards and disasters are prevalent since the beginning of civilization. Our earth has undergone tremendous changes due to calamitous events in various geological eras. Apart from scientific explanations of occurrence of disasters there are some religious texts which also have some explanations on the basis of their personal beliefs (Belshaw 1951; Keesing 1952; Kraus 2007; Levy et al. 2009; Singh 2020). Disasters are widespread phenomena and no one is immune from those, maybe it is spread of disease, act of terror, social unrest, or pandemic (for example COVID-19). Thus disasters have some serious consequences on community, nation, or individual.

The genesis of disasters has been explained in both religious philosophical and scientific exploration ways. Religious literatures depict them as the ill effect of man-environment relation in the form of nature curse in disobedience of natural laws set by nature. Nature- Laws- Man-Deeds- Outcomes are the process of nature–man relation. Such relationship of man and nature evolved three philosophical views like determinism, possibilism and new determinism in human geography (Hussain 1981). First two followed extreme opinions in the behaviour of human beings in man–nature relation. In the former case, man is considered as fully passive and nature dictates everything while the latter advocates the man as active and dominant over the nature. The third neo-determinism adopted the middle way explaining that nature dictates direction, laws and set the challenges, and man follows an adjusting way of wait and go. Religious literatures and the literature revealing the disasters genesis with theological approaches which lack scientific and analogical as well as systematic expression but provide the background for understanding and exploration of system and mechanism of occurrence of both natural and manmade disasters. Chester and Duncan expand Chester's (1998, 2005) early studies and assert that looking at disasters as acts of God and the punishment of deities mirrors the approach which dominates disaster studies and the way catastrophic events are considered as God–man relation. This view emphasizes victims' guilt and sinfulness, which is to be punished by nature's extremes. Such a conception of disasters is often associated with fatalistic and submissive attitudes that the proponents of the hazard paradigm quickly associate with a very low perception of risk (Gaillard and Texier 2010). It is thought that the philosophy of disaster as curse of God would develop the sense of helpless, non-responsive attitudes towards scientific disaster management development. Several studies on fatalism have long been applied to traditional and pre-industrial societies in Middle-Age Europe and to the contemporary so-called developing countries (Akasoy 2007; Burton et al. 1993; Kates et al. 1973; Schneider 1957). The exploitation of natural resources, mining and quarrying activities, deforestation as well as excess production of greenhouse gases are the examples of increasing lust of money which are responsible for both natural and manmade disasters in the world. Thus, man–nature relation is an important part of disaster management for preparedness and mitigation.

2 Disaster Management

The disaster is the negative impact of any natural, manmade or extreme emergencies on individual, community, society, nation and world. The degree and intensity as well as severity of the effect depend upon the level of vulnerability, the potential to cope with and sensitivity or response to the reduction of risk among the people, community and nation or concerned government and non-government institution/organization. All living species including animals, naturally, have the sense and capacity to protect them from adverse situations and ability to develop strategies for their existence or survival. There is struggle for survival but due to variation in ability and capability to cope with disaster, the concept of survival of the fittest prevailed. Human being is the super and the best creation of God that has the highest level of managerial ability to protect themselves from natural and unnatural hazards and disasters. All religious divine books of Jews, Christian, Muslim, Buddhist and Hindu stressed on paying charity, helping the deprived and victims and sacrifice for humanity with money, time and physical pains to save the nature, environment, human beings as well as animals and plants. Thus the natural disaster, hazards and the management or strategy for protection, prevention and reduction of disaster impacts and increasing awareness and response to disaster occurrence and remedial measures and step to reduce the risk, evacuation, rehabilitation and sustainable development were very much existed in different societies, communities, and nations but in very traditional, cultural and unscientific manners. The concept of disaster management and its need at different stages and different socio-economic scale must be acknowledged and propagated

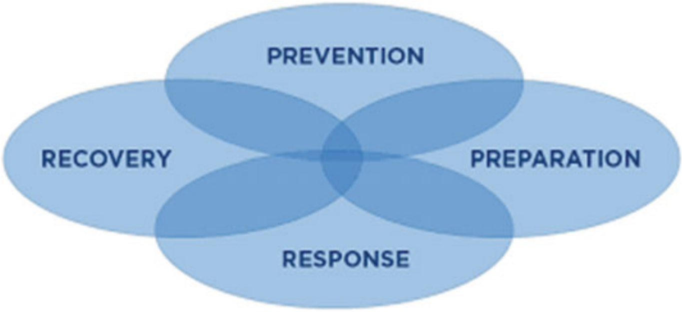

Fig. 1 Components of disaster management

for saving the lives, properties and environment from any kind of disasters. Disaster management is defined in the following ways.

Disaster management is how we deal with the human, material, economic or environmental impacts of the said disaster, it is the process of how we prepare for, respond to and learn from the effects of major failures (Elliott 2014). It is the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular, preparedness, response and recovery in order to lessen the impact of disasters (IFRC and RCS 2007). The disaster management includes all efforts pre- and post-occurrence of disaster with a view to minimize the impact, reducing risk, response to emergencies, rehabilitation of impacted people and building the disaster resilient society. Prevention, mitigation, preparedness, response, risk reduction, recovery and rehabilitation are important components of disaster management. In the broader sense, preparedness, response, recovery and prevention/ mitigation are known as components of disaster management (Fig. 1).

The disaster management could be operated into three stages or steps. Prevention and preparedness are the first pre-disaster operation of the disaster management. UNISDR viewed disaster prevention as the concept of engaging in activities which intend to prevent or avoid potential adverse impacts through action taken in advance, activities designed to provide protection from the occurrence of disasters. The first and most important activity is to enhance the knowledge and understanding of occurrence, genesis of hazards, methods of reduction of severity of the disaster and warn the people before outbreak of hazards, emergencies like disease, famines, pollution, epidemic, communal riot and political and socio-economic turmoil. Prevention/ mitigation and preparedness are pre-disaster management process. It is said prevention is better than cure. Preparedness to counter disaster's negative impact has been well acknowledged and instructed for an effort and preparation to prevent them from the risk of loss of life, property and environment even in historical past in various ancient civilizations. Propagation of curse or punishment of God on bad deeds and preventing the nation from wrong doing, pleasing the Almighty through charity, kindness, worship, duwa (mendicancy) through the spiritual activities construction of dams and levees in flood prone areas, construction of wooden house in seismic prone areas as well as cutting the mountains and making caves and house in protected leeward side in wind storm affected areas had been very common efforts towards prevention and mitigation of reduction of disaster's bad effects. Nature dictates all activities concerned with positive man–environment relation and beneficial to humanity. For example, man is not the owner of resource but trustee and it is the responsibility of resource rich people to spend their excess resource to meet the needs of poor and needy persons. These are noble guidelines for good deeds (Charity) mentioned in teaching of all important religions of the world. The pre-disaster activities should be well planned with education, wisdom, sincerity and faith. The most important purpose of this is to mitigate human loss. This also includes the development of information technology system; mobilization of resource for necessary action, assessment of disaster and issuance of a warning and to the people through media, radio, etc., transporting the people in a safe place in case of disaster occurrence. The occurrence of natural hazards and disasters are uncontrolled phenomena. Earthquake, volcanism, cyclones and tornados, landslides, floods and Tsunami cannot be stopped from occurring but minimize their impact intensity through improvement in mitigation and preparedness operations. Despite the high level of development of science and technology, the prediction of several natural disasters is partially successful.

Risk and damage could be reduced through reducing the vulnerability by development of residential areas in hazard free or less prone zone, construction of houses and other buildings following the disaster resistant technology as well as guaranteed food-security, social, economic and political security. Hazards are always prevalent, but the hazard becomes a disaster only when there is greater vulnerability and less capacity to cope with it. Capacity means and strengths which exist in households and communities and which enable them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster. All religions provide very rational and behavioural measures to reduce vulnerability and enhance the capacity to cope with hazards and disaster effects.

Regarding human activities, people must respect the rules of law and conduct accordingly at individualistic or collective level. Hoarding of food items for hiking price during drought and famine condition is strictly prohibited and considered a great crime in different religions as well as in humanity welfare-oriented concept. High value of responsive work is attributed to group work, social activities, social responsibilities, co-operation and consultation in various aspects of life, including giving full consideration and privilege to others. Strong emphasis should be given to group or community participation as a noble activity. This process of response in mitigation of disaster's risk reduction would unite the hearts of people and encourage participation of all concerned people happily with enthusiasm.

After the event of disasters, the process of quick action and the help of the victims of the disaster-prone areas are required. Response to disastrous conditions from various communities including government agencies, medical institutions and health personnel, social activists and NGOs is urgently needed. Transportation of victims from disaster affected areas, provision for emergency shelters, emergency medical facilities and care to victim's place and consolation about the losses are other activities urgently needed after the occurrence of disaster.

Disaster management with the consideration of public institution plans and strategy, scientific and technological approach as well as government policies could not alone achieve the target to reduce the risk, save the lives and property, manage safe place for displaced victims in the disaster affected areas. Local and indigenous as well traditional methods of managing and tackling the damage caused in, recovery and risk controlling measures as well as religious instructions and motivation for helping the victims through moral boosting, financial aiding, feeding and consoling should be included as essential components of disaster management. Community education, social awareness, realization of fulfilling responsibilities and sense of accountability as well as good and honest governance are very essential components of disaster management. Religious and cultural approaches could play pivotal roles in this direction. Consoling the victims, poor, patient and people in trouble especially in any disaster, both in natural and manmade are described as a pious work (Rewardable). Christianity, Hinduism, Buddhism and other religions advocate for charity, sacrifice for humanity, social wellbeing, helping the people. Human beings do not have any right to harm themselves or others. Causing harm or vulnerability to others is an unforgivable sin, unless the person who has been harmed, forgives the action (Ha 2015). Such knowledge and education will motivate the society and people and community and nation to reduce the risk, recovery, replacement, survival for food and health and later for rehabilitation and sustainable development of affected people and areas. Expert leadership and good governance is essential to the success of risk reduction programs. Risk cannot be reduced without knowledge and scientific management. Thus the role of people is to understand, believe and implement knowledge and follow the guidance and recommendations of experts.

3 Management of Vulnerability and Risk Reduction

Vulnerability refers the socio-economic, health and infrastructural conditions of a community, system or asset that make it susceptible to destructive and damaging effects of hazards of any nature. Poverty, social insecurity, political instability, food insecurity, poor house design and construction of buildings, lack of basic information and extension service, illiteracy, limited governmental concern and recognition of risk and bad governance are important determinants of the degree of vulnerability of people, community and society at any time and place (Hazard Vulnerability Research Institute 2015; Blaikie et al. 2004, ISDR). The physical profile like climate, topography, rock and soil structure,drainage pattern and flow and discharge of river's water and degree of mountain slope determine the level of vulnerability in response to preparedness, response and awareness of people, society, community and the government of concerned areas in the cases of various forms of disasters.. Physical, social, economic and environmental vulnerability are common categories in all forms of disasters and hazards.

Vulnerability status and its degree of seriousness varies significantly within the community, space and time as well as nature of hazards and natural as well as socio-economic environment of specific area (Cardona 2003). In the case of Natural geo-tectonic hazards like earthquake, tsunami and volcanic eruption, lack of early warning system, inhabitation in seismic prone areas and along the shallow coastlines, unawareness and careless attitudes towards disaster effects, unscientific design and construction of houses and the unpreparedness for reoccurring of such hazards have been important causes of high level of vulnerability (Calvi et al. 2006; Degg 1993). The development of settlement and built-up area along the foothills of landslide susceptible slope, deforestation, lack of bunds along the mountain slope to restrict water flow and erosion, poverty and unawareness about occurring highland oriented hazards are to be responsible for vulnerability to land slide and avalanche (Pallock and Wartman 2020). Poverty, social and food insecurity, unemployment and lack of government and NGO's support and aids increased the level of vulnerability when people were exposed to drought and famine hazards (Anderson and Woodrow 1991) while the environmental emergencies and extremes affect the people living near the toxic pollutants releasing establishments, in small non-ventilated and congested houses, below standard health and transport infrastructural facilities areas. These deficiencies in any area led to the vulnerable community and society in the case of exposing environment pollution and releasing of poisonous gases from chemical industries (Cozzani et al. 2006; Cardona 2007; Tahmid et al. 2020). Poverty, illiteracy, faith in superstitions, unhygienic food and drinking water, lack of medical facilities and accessibility and small and congested houses and polluted surrounding areas are the determinants of vulnerability of people and area while outbreak of epidemic or pandemic takes place. Similarly, elevation, slope, proximity to cyclone tract area, coastlines, forest cover, poverty, illiteracy, gender, muddy house and improper response are the reasons for cyclone-oriented vulnerability (Dewan 2013; Gallina et al. 2016; Sharma et al. 2018; Ali et al. 2020; Hoque et al. 2020). Flood disaster affected areas expose the venerable population and areas suffering from proper dams, early warning system, poverty, poor conditioned houses and inhabitation in low lying flood affect areas, and low education. Gender, age, socio-economic tradition as well as poor transport and medical infrastructure facilities are the indicators of vulnerability index for flood prone areas (Cardona 2003; Randoni et al. 2019; Deepak et al. 2020). The management of vulnerability needs to be designed separately for different forms of disasters keeping into consideration the reasons of vulnerability. Prescription of disease should be according to the diagnosis. Physical vulnerability is determined by population density, remoteness of settlement, site and material and structure of houses constructed in disaster-prone areas. The inability and adaptive capacity of people, community, organization, weak social interaction, incapable social institutions and system of cultural values to face and save the society from bad effects of disasters is referred as social vulnerability. In economic vulnerability, the level of vulnerability is highly dependent upon the economic status of individuals, communities and nations. The poor are usually more vulnerable to disasters because they lack the resources to build sturdy structures and put other engineering measures in place to protect themselves from being negatively impacted by disasters, whereas natural resource depletion and resource degradation are key aspects of environmental vulnerability. The vulnerability is the combined effect of exposure, sensitivity and

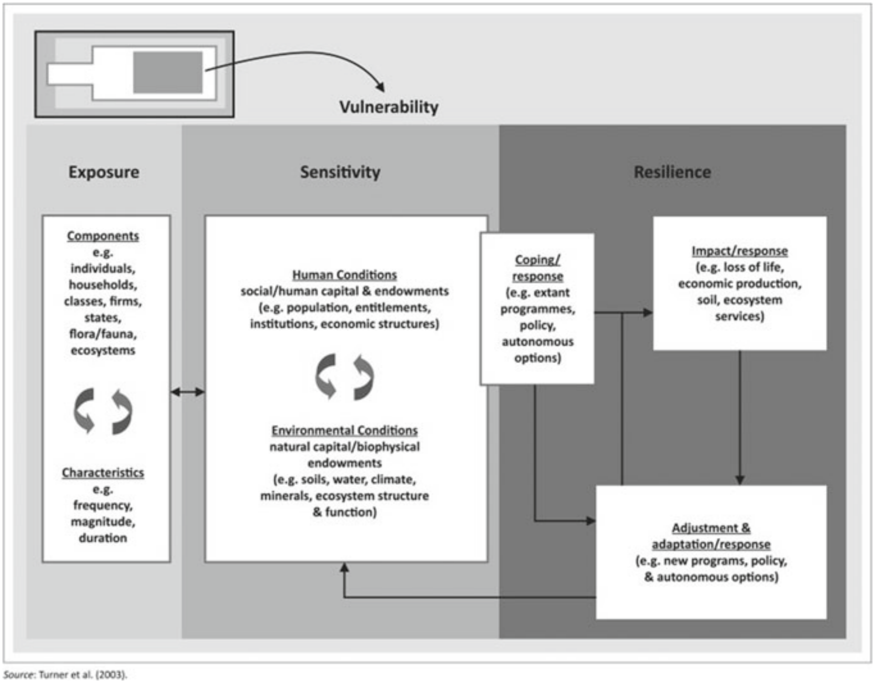

Fig. 2 Mechanism of development of vulnerability

resilience of the affected communities and regions. Turner et al. (2003) described the process and mechanism of development of vulnerability with reference to various forms of disasters as shown in Fig. 2.

Disaster risk is defined as the potential loss of life, injury or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. In the technical sense, it is defined through the combination of three terms: hazard, exposure and vulnerability (UNDRR). The degree and intensity of risk occurred in an exposed entity are the combined effects of vulnerability and level of preparedness and response of people, government and civil society and NGOs in any area. For example, during the second wave of COVID-19 in India great loss of life took place in response to unpreparedness of government to medical and health infrastructure and non-availability of medicines, oxygen, beds, vaccines and other allied services. Causalities are also added due to carelessness and no responsive behaviour of public, social and religious groups and political agencies towards severity and vaccination of COVID-19. Thus, the lack of preparedness, high degree of vulnerability especially resource-poor people and poor response of aid providing agencies, groups/communities as well as government at local administration tend to accelerate the disaster risk in areas exposed to particular hazards. Experience and studies reveal that vulnerability is the key factor determining the impact of disaster or risk occurrence. Fredrick Curry in his much acclaimed book *Disasters and Development* cites a classic example of how the vulnerability variation impacted the region differently even with hazards of same magnitudes. An earthquake of magnitude 6.4 occurred in San Fernando, California in 1971. In a city of over seven million people, only 58 deaths were reported. Two years later, a similar earthquake, registering a magnitude of 6.2 on the Richter scale, in Managua, Nicaragua reduced the centre of the city to rubble and killed over 6,000 people (Yamini 2006). Risk reduction does not need to make more focus on the hazards and the exposed people but on the vulnerability of exposed communities, systems, assets and environment (Birkman and MsMillan 2020).

Disaster management is one of the most important reasons to reduce the impact of disasters on humanity as well as nature. It aims to discover how the vulnerable section of society could be trained to cope with the adverse impacts of disasters through building disaster resilient societies. Good management practices are helpful in reducing the vulnerability of exposed communities and providing proper rehabilitation facilities in the event of disasters. The recent approach in disaster management has got a comprehensive view point wherein disaster risk reduction can be studied through vulnerability assessment, analysis, establishing future impact and measures to prevent the disasters' impacts on nature and living organisms including human beings. There are identified priority areas as per notification of UNDRR (1995) through Sendai framework for Disaster Risk Reduction 2015–30 with the goal of minimizing losses occurred due to the manifestation of natural hazards leading to disasters. The four priority areas include, understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster risk reduction for resilience and enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

4 Building Resilience Society: Towards Disaster Risk Reduction Management

The success of management of vulnerability and risk reduction as well as adverse impact on society depends upon the degree of development of capability and capacity as well as the ability of individuals, communities, organizations and states to adapt and tolerate to the occurrence of hazards and recover and safety from hazards, shocks, damage and stress without compromising long-term prospects for development (Baubion 2013). The described characteristics and capability to minimize disaster risk are referred to as disaster risk resilience. Various aspects and tools of building resilience capacity towards disaster risk reduction are technological capacity, skills and education levels, economic status and growth prospects, quality of environment and natural resource management institutions, livelihood assets, political structures and processes, infrastructure, flows of knowledge and information and speed and breadth of innovation (Yokomatsu and Stigler 2020) According to the Hyogo Framework for Action (UNISDR 2005), disaster resilience is determined by the degree to which individuals, communities and public and private organizations are capable of organizing themselves to learn from past disasters and reduce their risks to future ones, at international, regional, national and local levels. The origin of the concept of resilience as used in disaster risk research is often attributed to the work of Holling, who applied the concept to social-ecological systems (Holling 1973). This term was used first time in connection with disaster recovery after the earthquake in Shimoga city of Japan in 1954 (Alexander 2013). It is like immunity in the body to protect and resist from various diseases and especially epidemics. The United Nations International Strategy for Disaster Risk Reduction (UNISDR 2005) defines vulnerability as the susceptibility to the damaging effects of a hazard, and resilience as the ability to "resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner". The ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses—such as earthquakes, drought or violent conflict—without compromising their long-term prospects (DFID 2011). In conceptual terms, vulnerability and disaster resilience are closely related. Some authors see vulnerability as the opposite of disaster resilience, while others view vulnerability as a risk factor and disaster resilience as the capacity to respond (Manyena 2006).

The literature survey on disaster management revealed that the term resilience and its scope in dealing with the disaster challenges, gained momentum and relevance in response to increasing insecurity particularly in social and political turmoil and unrest; complexity and vulnerability in our everyday life. The Malta summit of civil societies of commonwealth countries in 2015 discussed the issues of developing resilient society and suggested the method of how to make a strong society resilient. Transformation, inclusion and responsiveness, transparency, accountability and gender equity have been considered as important tools for the development of resilience in various stakeholders of disaster management. Resilient society, resilient government, resilient economy, resilient environment, resilient science and resilient institution are different forms of disaster resilient buildings. Participatory approach among different agencies is an ideal process to build a confidence among people and communities in making progress to increase resilience and immunity for managing pre- and post-genesis of disasters. The linkage between public and private infrastructure and facilities would help in building disaster risk resilient society, community, government and nation to achieve the goal of sustainable development of people, economy, society and environment in disaster affected areas.

5 Building Disaster Risk Resilient Society from Bottom to Top

The disaster risk management through top to bottom process has not been succeeded at satisfactory level. It appears one way dictation from higher strata without preconceived challenges and reality at grassroots level in disaster prone and affected areas. Intention and sincerity, the spirit of any work, are generally less at top layer of management hierarchy which could not perform well in persuading the participants to do the work of risk control, rescue, relocation and food and medicine supply, etc., in disaster affected areas. The process of building disaster risk resilient people towards disasters should be strengthened from bottom to up. The following measures are required to reduce the risk and build disaster risk resilient society with persuasion and motivation of religious education and cultural attached sentiments along with technological and political and administrative efforts and endeavours.

- To develop a spirit of sacrifice and service among the stakeholders, related to disaster reduction management, towards poor and venerable communities
- Humanitarian approach development to tackle hazards and disaster effects. Encourage public private model (PPM) of humanitarian response.
- Honesty, sincerity and transparency in thinking and approach for help to people.
- Awareness and well training to people to handle situations during pre, present and post of disaster occurrence.
- Knowledge of cultural heritage and indigenous methods of preventing, reduction, recovery and rehabilitation techniques applied for vulnerability and risk reduction by local communities in the past.
- Strengthening communication linkage for understanding and utilization methods needed for safety of life and property resulted in due to hazards.
- Understanding of health care facilities and services available in the area especially for disaster period.
- Knowledge about various government and private institutions dealing aid, relief work, rehabilitation work and medical aid.
- Knowledge about various NGOs' and global agencies providing physical, financial and technological help to deal with disaster situation.
- Community and individual should subscribe insurance policy for protection of properties and belongings.

6 Conclusion

Disaster management is an inevitable need for every country to provide safety and security to her resources, people, animals and environment in crisis and tragedy that emerged out from disasters/hazards of any form. Natural as well human-induced frequency of disasters has been continuously increasing year after year, not only in developing and poor countries but also in developed countries of the world. The occurrence of hazards is uncontrolled phenomena. Prediction, preparedness, reduction in vulnerability, risk level and recovery and rehabilitation might have played positive role in the sustainable development of disaster affected people and area. The prediction and warning before striking in any area, need very scientific education, understanding and knowledge about the background of genesis of natural disasters like earthquakes, tornadoes, cyclones, floods, drought and landslides. Traditional knowledge in the forms of poetry, song, rituals and some astronomical appearances are important tools for early warning for happening of disasters. Education and guidelines of all religions could be acknowledged and utilized for better planning of disaster vulnerability and risk reduction management. Religion's role in different components of disaster management is worthy and appreciable especially in consoling, reducing vulnerability, recovery and providing food, heath and finance facilities. An integrated management in combination of disaster resilient society, engineers and scientists, government administration, social and religious activists as well as NGOs is urgently needed for achieving the goals of sustainable development in disaster affected areas. Building resilient and management of vulnerability is the key to reduction of disaster risk.

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Employability, A Key to Community's Socio-economic Malady of Pandemic Proportions

Ujwal Prakash

Abstract The development of any society in a region is dependent on the economic forum that is offered to them. It is for this reason that in a developing country regional inequality is progressively seen. The variability in the context of equality is the outcome of cumulative reasons that originates from the basic structure of economic, sociological, demographic, seasonal, or factors that calibrates to the minimum balance required for the community's sustenance. If these calibrations are hindered due to any external factors like a pandemic beyond control, the society witness severe imbalances which cast a functional impact on the economy and society that resonates with it. Intending to deal with such a situation demanding urgent attention, need-based arrangements have to be made to combat the adverse societal and economic effects of pandemics. During Covid-19 lockdown conditions in India, one of the most important aspects governing the sustainability of the community i.e., employment was severely hit and the worst impact was on informal employment. Considering that the informal sector contributed to about 45% of the gross domestic product in India, it becomes imperative to intrude into the situation. The present paper asserts this proposition and examines the socio-economic challenges faced by that section of the workforce who were dependent on daily wages for their sustenance but remained out of work since the lockdown conditions were imposed to contain the spread of Covid-19. With the help of the Qualitative Response Regression Model (linear probability model) based on focused group discussions, an assessment has been made to highlight their intrinsic requirements to assist them in pursuing a decent living. It was found that enhancing employability by supplementing employable skills among such workforce will enable a source of income that will counter the non-availability of work for them.

Keywords Employability · Informal employment conditions · Employment after lockdown · Pandemic · Community · Indian informal workforce

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U. Prakash (✉)
Department of Economics, Ranchi University, Ranchi, India
e-mail: ujwal.prakash@live.com

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1 Introduction

Human mankind is fragile to epidemics especially when its effect suppresses the entire community with social and economic consequences. Countries across the globe are facing one of the most infectious diseases in modern times in the form of the Covid-19 pandemic (Pandey et al. 2021). The community witnessed Covid-19 as a formidable opposing force for their sustenance and India was no exception. With a high population and its density, Covid-19 posed an exponential threat which was evident as the governmental measures proved inadequate to manage it in its early stages. Apart from the economic recession and related issues, one of the most acknowledgeable aspects of this global pandemic was observed in the developing countries where income-generating activities were the hardest hit leading to intense unemployment conditions in the economy. In the month of April 2020, the unemployment rate surged to 23.52% (Center for Monitoring Indian Economy 2021) as compared to 8.75% in March 2020, which was highest in the preceding years and was almost comparable with the situations of unemployment in India during a global recession in 2008 (Das 2008). Though with the passage of time and curative measures taken by the government, the unemployment rate came down in subsequent months still the effect of the Covid-19 pandemic was observed in every sector of the economy. The job loss, though was universal in both formal and informal sectors, its severity was intense in the informal sectors where the informal workers were unskilled and relied mostly on wages to meet their daily exigency needs. It was estimated that about 20% of the informal workers remained unemployed even after the lockdown conditions were lifted to revive the economy (Pandit 2021). Considering that contributions the informal sector makes to Gross Domestic Product (GDP) in India amounts to 45% (Kumar 2018) and it is the informal labor force that makes this happen, the unemployment percentage of 20 will have a contrary consequence on the economic growth of the country. This condition becomes linearly proportional to the socio-economic challenges that the community will be subjected to and comprehends that revival should start not only from tackling this deficiency in employment opportunity but also parallelly covering the base to offer a sustainable solution targeted specifically to the informal strata of the community.

The present study fosters to ascertain this situation and explores to identify workable conditions which will help the community to sustain such economic shocks in the future with the objectives to examine the socio-economic challenges faced by informal workers who remained out of work since the lockdown conditions were imposed to contain the spread of Covid-19 and to explore means which will assist them to sustain a living in the absence of wage-based regular or part-time work as an effect of pandemics that have severe economic consequences. These mandate governmental as well as private sector interventions to apply sustainable solutions to neutralize the challenges posed by the Covid-19 pandemic as it created a new sphere of observing the development process.

2 Framework of the Study

The essentiality of lockdown to contain the spread of Covid-19 across the globe is non-questionable, as it was intended to secure human mankind and its race. But the same cannot be confidently expressed considering the effect of lockdown measures due to the repercussions the Covid-19 constraint had on the economy and the society that forms it. The precautionary step of lockdown had the prerequisite to confine the members composing the society and restrict them from performing any economic activity leading to loss of business for the employer as the sectoral firms, industries, business units, etc., were comprehensively restricted with exemption only to the essential services providers. This considerable ceasing of business led the business firms to follow cost-cutting measures which triggered massive job loss across the country. Among the labor force in the country, informal workers were the hardest hit, as they were most vulnerable to such economic turbulences. Table 1 enumerates the status of employment as a comparative analysis in pre and post-lockdown conditions.

This assessment highlights the fact that in the post lockdown conditions, the unemployment percentage increased significantly. The informal workers with no work and depleted savings were forced to reverse migrate to their homeland during the lockdown. This mass exodus of the informal workers had compulsive repercussions on the agrarian employment settings in the rural economy. The return of the migrant laborers intensified the need to explore income generating activity among the rural households as their return was also accompanied by compulsions on three fronts, i.e., (i) loss in the source of income for the households, (ii) Addition of an extra member for the household, and (iii) Pressure on the limited agrarian work of the family already reeling under the problem of disguised and seasonal unemployment conditions.

These significant factors were a cohesive force that started to retard the living condition of households and widen the income inequality in the community as compared to those workers who did not migrate and settled with the agrarian work profile in their homeland. With the loss of income and status in the community, these workers were subject to social apathy which elevated the overall financial effect of job loss. Present condition prevalent in the rural Indian society which mostly abounds

Table 1 The status of employment of informal workers across sectors before and after lockdown

Sectors	Pre-lockdown			Post-lockdown		
	Unemployed	Seeking work	Working	Unemployed	Seeking work	Working
Agriculture	6.14	10.75	83.08	69.92	20.43	9.65
Construction	4.55	7.69	87.76	83.85	10.84	5.31
Manufacturing	2.22	5.12	92.66	79.96	13.07	9.97
Services	2.72	7.42	89.86	76.32	14.2	9.47

Source Action Aid India 2020 and firstpost.com in primary sector activity, typically in agriculture and poses a grim situation for most of the workers engaged in these activities as the problem of insufficient employment opportunities dominate the agendas which the government need to tackle along with streamlining agricultural marketing to boost farmers income. It is mandated to explore this situation and optimize their value toward enabling them to sustain a decent living by overcoming the growth retarding economic and social factors relating to economic shocks like pandemics. It is the responsibility of the Government as well as the society to assist in the process of integrating these workforces which were left behind in the growth process, where they are empowered to secure growth for themselves and also contribute toward the development of the country as a whole.

3 Research Methodology

3.1 Data Base for the Study

The study is based on primary data which was collected by questionnaire through an informed enumerator and the study area was confined to Sonahatu block of Jharkhand State. This area abounds in reversed migrants from various urban parts of metropolitan cities of the country as well as from Ranchi, the capital city of Jharkhand. Moreover, others lost their job (informal in nature) during the Covid-19 lockdown but were unable to revive their employment prospects in the post lockdown conditions and mostly confined their income generation from the farm and related activity. These workers from the defined area formed the study population and a sample size of 50 workers was taken to administer the survey. All the workers in the sample were informed and guided about the present condition of employment opportunities in the post lockdown and also, they were guided on the ways to employ their labor in better income generation activity. The sample was subjected to focus group discussion in two separate groups and their views were recorded. The respondent's profile is presented in Table 2. Out of the total respondents, 46 were male candidates and 4 were female.

Table 2 Respondent's profile

Gender		Education		Present income	
Male	46	Post graduate	15	No income	28
Female	4	Graduate	21	0 to 1000	11
Other	0	Intermediate	9	1000 to 3000	5
		Matriculation	5	3000 to 7000	6

Source Author's Survey

Concerning the education of the respondents in the study, 15 were educated with a post-graduation degree, 21 were graduates, 9 had completed their study till intermediate and the rest were matriculated. Concerning the income of the respondents, 28 of them did not have any specific source of income, 11 had the income range of 0–1000 rupees per month, 5 were in the income group of rupees 1000–3000, whereas 6 were in the income range of rupees 3000–7000.

3.2 Theory and Calculation

The research conducted was motivated by the Human Capital Theory considering how education along with other characteristics help create skills and individuals from human capital by acting in their interest (Hung and Ramsden 2021). The employability enhancement enforces an individual to accumulate skills required to foster self-aspiration of meaningful employment. It also concerns an individual potential in the labor market as a realization of employment potential (Van Harten et al. 2021). In the quest to establish a forum for this study, Linear Probability Model (LPM) was applied in the data analysis. The LPM is the application of ordinary least squares to binary outcomes in the data (Deke 2014). The present study comprised estimating regression parameters based on binary data obtained from the respondents.

3.3 Data Analysis

The qualitative research technique of naturalistic observational analysis was used to observe respondents' ongoing discussion and behavior in their natural surroundings. Table 3 records the remark of respondents from the focused group discussion. Naturalistic observation made during the focused group discussion highlighted the socio-economic plight of the informal workers in the study area. The socio-economic indicators of expanding inequality, poverty, unemployment, unsustainable present work, inability to support family, and inequality of opportunity recorded 100% responses from the informants. Inferential statistics comprising the quality response regression model (linear probability model—LPM) was applied to the data to interpret the results to construe the objectives. The respondents were asked to state an income that will give them comfort at their home and suggest measures for their self-improvement to assist them in gaining employment that will give them their desired income at home. The respondents were asked for their view if enhancing their employability by imbibing a set of skills will help them either to gain employment or start their ventures at a micro-level. They were again asked to assign 1 if they believed that enhancing employability will increase their chances to gain work and 0 if they do not believe so. The data obtained was subjected to LPM and a regression Eq. (1) was obtained (Gujarati et al. 2018):

Table 3 Respondent's remark on socio-economic indicators

Socio-economic indicators	Responses
Poverty	50
Discrimination	44
Expanding inequality	50
Unemployment	50
Health issues	23
Unsustainable present work	50
Inability to support the family	50
Inequality in social class	41
Inequality of opportunity	50
Achievement deprivation	30
Neighborhood deprivation	12

Source Researcher's survey

$$\widehat{Y_i} = -0.5677 + 0.0744X_i \quad (1)$$

The regression equation was derived from the data in the Table 4. Table 4 reports the result of the survey and mentions the respondent's remark on employability as a determinant of prospects in employment. R in the table indicates the respondent's serial number, Y is the response of the informants, where numeric figure 1 indicates yes and 2 indicates no. Whereas, X indicated the expected income. Y_i in Table 4 is the estimated value of Y.

In Eq. (1) the intercept of −0.5677 gives the probability that the respondent with zero desired income will opt to enhance employability. Since this value is negative, it is being treated as zero. This was necessitated as the OLS (ordinary least square) procedure does not follow the inequality restriction:

$$0 \leq (EY_i) \leq 1$$

The slope value of 0.0744 means that for a unit change in expected income ('000 in the study), on average the probability of respondents opting to enhance their employability increases by merely 0.0744 or about 7%. Each respondent's actual probability is enumerated in Table 4.

4 Findings and Discussion

It was evident from the analysis through the focused group discussion that suppression among the workers taken under this study was observable. The clear incidence of adverse economic factors on the social life of these workers was profound which was acting as a physical as well as a mental constraint in their quest to secure a

Table 4 Informant's response on employability as a determinant of employment prospects

R	Y	X	(Y_i)	R	Y	X	(Y_i)	R	Y	X	(Y_i)
1	1	20	0.9203	19	1	15	0.5483	37	0	15	0.5483
2	1	15	0.5483	20	1	20	0.9203	38	0	12	0.3251
3	0	15	0.5483	21	1	15	0.5483	39	1	15	0.5483
4	0	12	0.3251	22	1	20	0.9203	40	1	13	0.3995
5	1	15	0.5483	23	0	13	0.3995	41	0	10	0.1763
6	0	13	0.3995	24	0	14	0.4739	42	1	15	0.5483
7	1	10	0.1763	25	1	20	0.9203	43	0	20	0.9203
8	1	15	0.5483	26	0	12	0.3251	44	1	15	0.5483
9	1	20	0.9203	27	0	10	0.1763	45	0	13	0.3995
10	1	15	0.5483	28	1	15	0.5483	46	1	20	0.9203
11	0	15	0.5483	29	1	20	0.9203	47	1	15	0.5483
12	1	20	0.9203	30	1	15	0.5483	48	1	20	0.9203
13	1	15	0.5483	31	0	15	0.5483	49	0	10	0.1763
14	1	20	0.9203	32	1	20	0.9203	50	0	15	0.5483
15	1	20	0.9203	33	0	15	0.5483				
16	0	15	0.5483	34	1	20	0.9203				
17	1	15	0.5483	35	0	20	0.9203				
18	0	12	0.3251	36	1	15	0.5483				

Source Researcher's Survey

decent living for themselves and their family as compared with those workers who managed to get a job in the post lockdown conditions and those who did not migrate and stayed in their homeland. Suppression of any kind whether physical, mental, or monetary, is not conducive for the well-being of the community. This affects human development which in turn slows the human capital formation among the countrymen casting negative repercussions on the economic growth of the country. Human capital formation is a key element in enhancing employability. From the second assessment by the application of LPM, it was deduced that in the absence of employable skills these workers were vulnerable to the vagaries of economic shocks in the future. Even with an increase in their desired income by 1000 rupees, there seemed a very small change in their mindset to intensify their demand for enhancing employability. This observation was noteworthy as despite most of the respondents agreeing on employability as the factor that may ensure them decent work, their probability to raise its demand was negligent. This can be attributed to two basic factors:

(a) Lack of belief in the administrative machinery that will channelize such skill-based vocational programs to enhance employability.
(b) They might be more inclined to handle whatever work they have rather than investing time in vocational job-oriented courses which in turn may leave no time for any vocational training.

5 Conclusions

For a massive populous country like India, it is imperative to address the cause of unemployment. Covid-19 proved the vulnerability of the workers to economic shocks and raised questions on the future of the informal workers. It also underscores the feeble employment fabric that the current economy wears. The question that needs to be addressed is, how will the informal workers be protected in case such pandemics or economic shocks surfaces again? Answering this question will not only assist the informal workers but also enhance their contributions to the GDP, an indicator of economic development. The present study with the informal workers expressed that enhancing employability by making people as resources will help to immune them from such economic turbulences in the future as the probability of job loss in case of a generic work always remains high as compared to jobs with specialized work. Even in cases, there is a job loss, the trained workers will still possess the skill which can be used to realign their employment. The focus on employability and raising the human capital among the informal workers can be affected not only by governmental intervention but also by public–private partnership wherein the leaders in the private sector can be roped in through their corporate social responsibility initiatives to impart vocational training that is based on the skill set and specialization the worker is longing for. This study was subjected to certain limitations which comprised restricting the research field only to one block of Ranchi district. The analysis in the paper is based on self-report. Since the sample size was small and respondents from different sections of the community were not equal, a comprehensive analysis could not be done. To comprehend the findings of this paper, an expansionary analysis is deemed to cover more districts and obtain larger samples more equitably.

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Living with Floods: Community-Based Coping and Resilience Mechanism of Mising from Floods; A Study of Majuli District of Assam

Bikash Chetry

Abstract Over the years, natural disasters have acquired an anthropomorphic character as community has become exponentially vulnerable to hazards. The nature, character and extent of disasters are unique in context of the Brahmaputra valley due to vast river networks. The climate changes' adaptation practices have been state-driven and followed a technocratic approach or developed keeping aside the Indigenous community's faith, cultural practices, livelihood changes, etc. Hence, the impact of disasters has been long-lasting on the Particularly Vulnerable Tribal/Indigenous Groups (PVTGs). Also, the disaster policies and programmes were not necessarily in sync with the authenticities or standpoint of local or aboriginal communities which inclines it to miss out on the Indigenous perspective. Climate change adaptation should outwit far from the discourse of methodical or scientific knowledge or the following technocratic approach (Lefale 2008), but should integrate Indigenous knowledge too as part of disaster planning, preparing and a coping mechanism as well. Local knowledge not only fosters success of the intervention in vulnerable geographies beside significantly contributing towards the sustainable practice among the communities living in vulnerable topographies or with flood but also has found their Indigenous mechanism useful for ecosystem restoration where ingredients of adaptive management and islanders have shown a significant ingenuity in their coping mechanism. The livelihood strategies and community-based adaptation practices have been a significant source of sustenance from floods. Considering the participation and integration of these knowledge keys is a necessary means for community-based disaster management and to pursue the Sendai Framework for Action. This paper intends to locate how the Indigenous/tribal communities of Majuli negotiate with the everyday precarities and use their Indigenous practices not only to save their life but also to prepare themselves before the floods. It also explores the narratives of community-owned solutions for disaster management, their livelihood strategies and adaptive practices for sustenance from floods. The analysis of data also depicts that Mising/Mishing community have mastered these traditional methods of healing practices or magico-religious practices to treat ailments by using herbs in the form of the fresh drug, but in modern-day disaster management plan,

B. Chetry (✉)
Department of Social Development, University of Cape Town, Cape Town, South Africa
e-mail: chtbik001@myuct.ac.za; chetry.bikash@gmail.com

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these knowledge base doesn't find a place or they are not dimmed relevant, as the practices are continued to be labelled as being primitive rather than understanding it's significance among Indigenous communities. Hence, through this paper, I will throw light on why Disaster Management plans for disaster risk reduction plans to necessitate the integration of local or native knowledge which is made for locals that has evolved over a while by inculcating their needs and ecology and this wisdom or knowledge requires an urgent reckoning. Therefore, through the study, I attempted to highlight how technocratic approaches are more beneficial for certain communities but not necessarily for the vulnerable constituency.

Keywords Floods · Community-based practices · Community based resilience and coping mechanism · Indigenous knowledge/wisdoms and faith · Mising · Majuli · Assam

1 Introduction

Between the 1990s and 2001, the world faced 50% of hydrological disasters mostly floods and Asia alone endured 35% of these hydrological calamities throughout the term (UNESCO Office Bangkok & Regional Bureau for Education in Asia & the Pacific 2006). Nearly 90% of the natural disasters occur in developing countries, and these countries account for 95% of deaths which occur due to these disasters. The second half of twentieth century witnessed more than 200 natural disasters in different parts of the world which in turn took 1.4 million's lives. Losses due to natural disasters have been 20 times more than their GDP in the developing countries and Asia tops in this list, and hydrological deluge or calamities has been perennial phenomena in the Indo-Gangetic-Brahmaputra valley. Due to these deluge years, typically, hundreds and thousands of lives are lost and cultivated land, crops are damaged, a large section of communities are rendered homeless or thousands of livestock are lost to disasters (Government of India 2009). Especially nation-state like India that's highly susceptible or vulnerable to deluge of natural origin leads to loss to the tune of about 2% GDP (World Bank survey Year NA, cited from (UNDP and Government of India 2009–2012)) on an average occurs due to disasters. This is a huge loss and it impedes the developmental thrust significantly. A large part of resources, which otherwise could be used for development has to be allocated to disaster management and reconstruction work. Assam is the land of the Brahmaputra River and its tributaries; due to the vast river networks, it has been vulnerable to hydrological calamities like floods and riverbank erosion over decades (Berkes 2003).

Two major rivers of Assam, the Brahmaputra and the Barak have more than 50 tributaries which lead to the deluge, especially during the rainy season every year. About 10.2% of the entire year, the country is prone to floods and riverbank erosion, however, this is four times more in the state of Assam than the national average of flood-affected areas of the country, i.e. 39.58% (Rastriya Barh Ayog Report 1999). Field study, Majuli Island, is one of the most perennial flood-affected districts of

Assam. As prior to the 1950 earthquake, island had a surface area of about 1256 sq. km in 1853, but it's shrunk to 421.65 sq. km by 2001 due to flood and riverbank erosion (Nath 2008). Majuli, a riverine island located on the upper reaches of the Brahmaputra, has been portrayed as an isle looming for catastrophe by the present-day report published by state and non-state bodies also through different electronic and print media. It is significant to understand that this peril has been menacing the island's very existence and riverbank erosion in the state.

Indigenous knowledge (IK) and practices are defined as '*a form of knowledge base which existed in the community or knowledge which acquired by the community over years based on their lived experiences, co-existence with nature, practices, rituals, folklore, chants and traditional institutions etc. which has been passed on them from through different mean by the elders and other community member*' (Mercer et al. 2010). Also, these knowledges, wisdoms of the Indigenous communities are embedded in the culture and tradition as well (Wisner 1995) most of these practices are developed because of their daily engagement with nature which gets expressed during natural resource management or deluge (Cajete 2000). Unlike any other supplementary manifestation of local wisdoms/knowledge and practices IK and practices, these are too highly gendered or often grounded based on the indicators of supremacy, powers and positionality like age, caste and class of different constituencies (Lopez-Caressi et al. 2014). The field data show, unlike most other Indigenous communities, in the Misings community as well the 'Keeper of the wisdom' i.e., community elders, healers, practitioners, etc. have been passing on the majority of the Indigeneity, knowledge base, and wisdom orally from generation to another. And this evolving knowledge base has been passed on to the community through folklore, stories of myths and legends, songs, chants, etc. These have been a key archival tool for researchers studying the IK system and practices of community.

Historically, the governance strategies for emergency management are largely governed by administration/regime, transcontinental non-profits and industries in particular (Ostrom and Cox 2010; Cox et al. 2010a, b) wherein top-down approach is largely followed which is largely controlled by experts from different fields and these strategies or programmes clearly deem to oversee the role of local or Indigenous practices or Indigenous leader, elders, etc. (Dryzek 2005), and also tends to miss out the Indigenous or local community perspective in disaster planning. The scholarships in DRR and also the literature endorses the duality among the local wisdom/knowledge and empirical methodology by foregrounding the dissimilarity between these forms of wisdoms or information which affects disaster management practices. The indicated difference in literature or practice marginalizes the IK systems and gives more preference to the scientific knowledge as it is a more rational, objective and advanced response to the deluge or projects scientific knowledge superior in nature to IK and wisdoms and kept it out from the scientific realm. While ignoring the opportunities that IK offers completely in DRR and towards the development process (Briggs 2005) including agriculture (Biggelaar 1991), natural resources (Dewalt 1994) and DRR (Mercer et al. 2010) Although contrarily, local wisdom and traditional knowledge critique this dichotomy as we often have seen in vulnerable geographies people relying on the wisdoms for preparedness and coping. The state-led initiative has been following a more technocratic approach (creating embankment, spurs, check dams, etc.) without integrating the Indigenous communities in these disaster risk reduction plans or their voice and need which is why it couldn't reduce much of the isle impact caused due to hazards (Felding 2013; D'Souza 2006). Integrating IK systems and wisdoms in disasters risk reduction are imperative for establishing harmony between communities and their conservation practices into ecosystem governance, protecting the sacred forest, deforestation, reducing the carbon footprints, understanding climate changing and adapting sustainable practices to cope from these changes as well that recognizes the community right and access to resources, etc. (Hill et al. 2020). The diverse knowledge and wisdoms of the communities have been instrumental in safeguarding ecosystem and well-being of communities and individuals across the globe (Díaz et al. 2019), as more than 36% forest cover of the world is still intact or sustainably managed by the Indigenous communities (Fa et al. 2020). Hereafter, it's imperative for assimilation of these practices and knowledge bases including local knowledge bases, wisdoms and scientific/modern-day practices, and DRR should go hand in hand in order to develop resilience mechanism of Indigenous communities to disasters (Pottier et al. 2003; Shaw et al. 2009).

There has been growing acknowledgement of the augmented and unequalled environmental deterioration since the 1980s (Millennium Ecosystem Assessment and World Health Organization 2005), while at the same time, there are supporting evidence which show how Indigenous communities have been leading a significant role in devising disasters resilient methodology and sustainable natural resource management practices in the community (Agrawal 2003; Berkes 2007; Bloom et al. 2010; Ostrom and Cox 2010; UNDP 2012). The coping mechanism and solutions of native communities in order to deal with disasters has been progressively observed to be evolving from around the globe. However, there have been numerous communities which possess IK and practices for disaster risk reduction and natural resources management however, there is a parallel need to internalize these practices with the Disaster Management plans at both local and national levels. Many of these traditional ecological knowledge and practices are conditions for context-specific issue, their application, their strategy philosophies, analysing numerous native social–ecological schemes which include community property resources management, management and protection of sacred forest, traditional institutions, fisheries, etc. (Cox et al. 2010a, b; Galappaththi and Berkes 2015; Poteete and Ostrom 2004). For decades, the diverse communities in various hazard-prone areas of South Asia have learnt to cope with disasters and also in reducing the risks of natural disasters through their IK. They have inherited these practices originated in the communities through their experiences and are based out on local needs and culture. This vast knowledge that gets transmitted verbally from one generation to another through speech, songs which are mostly in form of chants, proses, stories or verses, etc., has helped in building the community resilience and enhancing their coping mechanisms. IK needs to be understood with communities' relation with their habitat, locale, forest, stream, river animals, etc., with whom they live and co-exist in harmony and their ways of using these resources to cope with disasters (Walker et al. 2010). Local wisdom or knowledge doesn't only contribute to the accomplishment of the initiatives in disaster risk reduction but also contributes prominently to addressing the sustainability within the community for an extended tenure. So, it is pertinent that not only their practices but also Indigenous or local communities should be integrated or their participation needs to be encouraged in disaster risk reduction practices which are requisite for pursuing the Hyogo Framework for Action or Sendai Framework for Action and to attain the Sustainable Development Goals as well. These development goals and actions are vital as they highlight the significance of local knowledge in DRR and also mainstream in disaster management practices or promote long-term development programmes which are disaster resilient.

Traditional knowledge systems or IK have always been a powerful tool for Indigenous communities. It has always helped local people, in protecting and conserving their natural resources, restoring their livelihoods and lives from disasters. After the 2004 Tsunami in the Indian Ocean, there were many stories of accomplishment/achievements which appeared, that brought attention towards the scholarship of local knowledge and wisdom which has been used for disaster risk reduction. The significance of native or local knowledge or practices has always assisted to cope or prepare for deluges and mainstream disaster risk reduction policies and practices.

Local knowledge plays a significant part in disaster risk reduction in local or global context. Construction of house is one of the vital Indigenous technologies, and South Asian countries have also been an area with a large pool of local or native knowledge-based practices due to their large number of Indigenous populations. For example, Kashmir valley has notable housing structure which is earthquake-resilient and there are two types of housing structure which are quite predominant in the valley, i.e. Taq System (which is constructed by timber laced masonry) and Dhajji or Dewain (in which timber frames are made within the fill walls of the house) which aids the community in order to protect their lives from deluges. Many researchers have reported that native or local housing structures or building practices of the community have aided in preventing the collapse of houses, especially in areas with high seismicity zones in different parts of the country. Like the traditional housing structure of Uttarakhand Koti Banal architecture, *Bhongas* Kutchi types of houses, or brick in-fill in half-timbered constructions of houses in Himachal Pradesh or bamboo-based houses are constructed in Assam which are known as *Ekra* or *Ikra* (in which the wall of the house is made from bamboos). In the flood-affected areas of Assam and other North-eastern states, the local community constructs *Stilts* (Chang Ghar) so that water during the deluge can effortlessly pass through underneath the house.

This paper is an attempt to explore the collective accounts or their narratives about community possessed practice and solutions which has aided the community in order to reduce the impact of disasters or to cope with disasters. Governance, administration and management of resources, land, community property resource, etc., while strengthening community-owned sustainable practices have engendered a feeling of pride, especially among local community about traditional knowledge and practices, etc., which aids in coping from the deluge every year in Majuli.

2 Locale of Research and Epistemology

The word '*Majuli*' is a geographical term which means a cultivated land in the middle of the fresh water course. It is encircled by the Brahmaputra in the South and Lohit, Kherketia Suti, Subansiri in the North. It lies between 94° 10′ 25″ N 27° 06′ 11″ E and 94° 31′ 10″ N 27° 05′ 09″ E. Majuli is also known as the '*Cultural hub of Assam*' as its rich folk and cultural outlook of the riverine island manifests fusion of Vaishnavism and Indigenous tradition and practices due to the institution of Neo-Vaishnavism[1] established in the sixteenth century A.D. by the renowned bhakti saint Shri Sankaradeva who made the island sacred and one of the most venerate places of Assam. However, perennial flooding and riverbank erosion has led into massive loss in the island not only economically or socially but also in terms of loss of cultural heritage and folk practices, traditional livelihood, etc. These losses possess a serious threat towards the rich social and cultural significance or tradition of the island because of twin process of flood and erosion as majority of the Satras[2] have been shifted from the north bank of the Brahmaputra valley.

While doing research among the Indigenous communities, it is pertinent to remember that such research is built on the relationship of trust between the researchers and the subjects which takes places in different spaces in the community (Noblit et al. 2004) which is a significant part of the community like gathering or meeting of the elders in the community halls, bonfire, during rituals and functions of the villages wherein often the stories about the legends, myths, evils, etc., are shared with the help of elder's chants, riddles and story-telling, etc. Hence, Indigenous epistemology needs to be looked as a critical methodology to conduct research or its tendency which often tends to ignore the local community's traditional knowledge (Denzin et al. 2008) and continues to restrict knowledge production to natural science (Smith 1999).

The research was ethnographic in nature with an aim to get an in-depth understanding of 'Community based coping and resilience mechanism of Mising community from floods' so that it can contribute towards the existing disaster scholarship in adopting more community-based approach in disaster risk reduction. The site selected for the research is Majuli which was selected using the purposive sampling method and through review of secondary data. As per the Flood Hazard Atlas of Assam, ISRO 2011 in Assam State Disaster Management Plan 2013,[3] Majuli district is perennially affected by floods as 40–50% of the area was severely impacted by flood hazards between 1998 and 2017 which was also one of the criteria for the selection of

[1] It was a movement which was spearheaded by Bhakti Saints Mahapurux Srimanta Sankaradeva (1449–1568 A.D.) as it was great socio-cultural revolution in Assam with an aim of upliftment of backward classes and minimization of rigidity of caste distinction. Through the movement, he spread the idea '*Ek sarna Naam Dharma*' (existence of one God).

[2] Satras are Mahapuruxiya monasteries established by the great Bhakti Saints Mahapurux Srimanta Sankaradeva (1449–1568 A.D.), Mahapurusha Madhavdev and their disciples and followers in Assam. The Institution of Satra is a unique feature of Vaishnavism in Assam. The chief of a Satra is called a Satradhikar. The Satras are not just monasteries, but centres of traditional performing arts.

[3] The report can be found in http://asdma.gov.in/pdf/asdmp.pdf.

this district. For the research, I used explorative interviews with the key informants from the community and the participants included community elders, healer, member of traditional institutions, men, women, local scholars and representative from village councils, etc. The data collection was done through key informant's interviews and a checklist[4] was used for the interview (semi-structured questions were used to interview members of flood-affected households to enquire about community-based coping and resilience mechanism as well).

2.1 *Effect of Climate Change on the Island*

Last few decades, climate change and its impacts have become the buzz word and it gained utmost significance as different researches show a considerable indication of climate changes, in the recent past, we have seen a rise in global temperature, floods, droughts, erratic rainfall, cyclone becoming more and more rampant as well (American Meteorological Society 2012; Norris et al. 2008; Agrawal and Perrin 2008; Paavola 2008; IPCC 2014; UNFCCC 2007; Adger and Kelly 1999). The impact of climate change can be seen on the majority of the countries due to changing weather conditions, rising level of the sea, forest fires, etc. In 2020, world witnessed some of the greatest disasters: Cyclone Amphan in India, Australia's Black Summer, Indonesia's flash floods, earthquake in Turkey, etc. This in turn has impacted lives, livelihoods and economies of the countries, and a large part of the resources which could be used for countries' growth has to be utilized for relief and reconstruction. However, the impact of climatic changes on countries was seen to be disproportionate as the developed countries witnessed 18 days or less than that of extreme weather every year within life due to climate crisis, while on contrary, the developing world faces 100 days or more days of extreme weather condition. And in between 1951 and 2000, India witnessed a high number of disasters due to high-intensity rainfall (Goswami et al. 2006), as cyclone intensity has augmented by approximately 2–4° of warmer temperature for 10–20% in different nation-states of Asia and its neighbouring states as well (Cruz et al. 2007). Hence, the burden caused due to the climate change is not evenly distributed among countries as the impact is seen more in developing countries compared to developed countries as the formed countries' economies are dependent on climate-sensitive livelihood practices like agriculture dependent on rainfall, water forestry, etc. (Moorhead 2009; Parker et al. 2019). Furthermore, the communities in these geographies are more susceptible or their vulnerabilities due to limited livelihood opportunities or choices, small land holdings, access to markets, etc. Even the Human Development Report of 2020 advocates for sustainable development or transformation which should not only increase human freedom but also

[4] Some of the key points of the checklist were types of disasters and hazards in the area, impact of disaster on traditional livelihoods (Block level, GP level and community level), Indigenous knowledge and practices to cope from disasters, role of institutions in disaster risk management strengths of the community, etc.

diminish the planetary pressure (UNDP 2020). The data from this account shows that the effect of climate changes can be seen more in developing and least developed countries compared to developed as the cost associated with recovery from the changes will be more on developing countries impacting the achievement towards Sustainable Development Goals for poverty reduction, food security, migration, etc.

The impact of climate change can be seen more in rural economies and hinterlands around the world compared to urban areas as the people are primarily dependent on agriculture, fishing, other forms of livelihood and for food and fodder the communities are largely dependent on natural resources and climatic conditions. Hence, their life, livestock, food practices, livelihood, etc., are affected by the changes due to the socio-cultural environment including the biotic and abiotic environment. The gradual rise of temperature in the Global South including Asia and Africa due to changing climatic conditions will result in various disasters like floods, droughts, erratic rainfall, storms, cyclone, etc., which will render more than 150 million to be displaced due to climate-induced factors by 2050 and also affect the agricultural productivity at the same time. These have led to a grave impact on the rural populations as the absence of policies in the state, has rendered much of lands uncultivable and led to the loss of livelihood as well. Due to the result of climate crisis and changing climate, it is predicted that it would impact the production of agricultural produce in different nation-states of South Asia, e.g. cereal production was reduced by 4–10% by 2100 under the conservation practices of IPCC (Cruz et al. 2007). Other research also reported that yield and rates of poverty as well had a negative correlation. In the year 2018, the UN's Food and Agricultural Organization (FAO) reported that climate change is one of the underlying factors for rising global hunger and decreasing agricultural output as well (IPCC 2014) which was also concurred by the report by Intergovernmental Panel on Climate Change (IPCC) depicts that by the end of 2050, more than 80 million people would face extreme hunger (IPCC 2014).

The Brahmaputra and its tributaries are important sources for the lives and livelihoods of the community and their well-being in the valley as the most prominent activities have been dependent on rivers and monsoons for centuries for agricultural production, fishing, pottery making animal husbandry, etc. So, the common social classes like peasants, potters fishermen, etc., have been dependent on rivers. But over the years due to climate change and erratic rainfall, the valley has witnessed some of the most devastating floods in the recent past (Apurv et al. 2015). The state's floodplain has been perennially affected due to deluge (Saikia 2019) and as per the Central Water Commission report, the loss tune to that between 1953 and 2011 was approximately 3521 million of immovable property, standing crops, houses, livestock and other loss in the state (India Water Portal 2012). The rivers have not only brought loss of life, economic loss but also threat of losing traditional livelihoods like pottery making, mask making cultures which is unique for the geographies like Majuli or for that matter weaving and tribal handicrafts of Mising and Deoris from Dhemaji and Lakhimpur. The Brahmaputra has brought significant changes in the last decades in the social–cultural fabric of Assamese society as well. Besides these, the impact of climate changes is also visible in the Brahmaputra valley like increase in temperature, surge in peak flow annually, unpredictable rainfall and monsoon seasons in the last few decades has led to the adverse impact on the vulnerable constituencies' traditional livelihood practices as well (Pervez and Henebry 2014).

The river island has been perennially affected by the twin process of flood and riverbank erosion (Goswami et al. 2020). As discussed in the earlier section as well, the island's total landmass was approximately around 1,265 sq. km in 1891, which was reduced to 421.68 sq. km in 2001 due to the riverbank erosion by the Brahmaputra, Kherkutia Xuti and other tributaries as well (Sarma and Phukan 2004) and the erosion has been caused in most of char and chapori areas or to the areas in proximity to riverbank (Roy et al. 2020). Post the 1950 earthquake in Assam, it led to the rise in the Brahmaputra riverbed by 3–4 m due to the deposition of heavy siltation and due to southwest monsoon, which has resulted in perennial flooding and erosion in the state (Kotoky et al. 2003). Even the District Disaster Management Plan of Majuli reported that, in the last three decades, more than 69 villages were eroded from the isle due to rampant riverbank erosion caused by the Brahmaputra and more than 96 villages are deemed to be vulnerable due to inundating and erosion caused due to it (Government of Assam 2019). The twin process of deluge like inundation and erosion caused by the Brahmaputra has not only affected the lives and livelihood of the community but also impacted the social–cultural fabric of the state as well. Out of 65 Satras (Vaishnavities monasteries), only 23 Satras are survived now, the rest are eroded due to riverbank erosion or being shifted to nearby districts (Sarma and Phukan 2004; Sarma 2013). Even the average income of the families has been impacted. An income of 40 USD per month has been declined in the last few years as it has retheorized the livelihood practices, reduced agricultural productivity, fishing, potter making, etc., of the community due to frequent floods, erosion and siltation. In the island more than 75% of population is dependent on farming and allied activities, and due to the twin process of the flood and riverbank erosion every year, a large area of the agricultural land is eroded along with standing crops every year. Along with farming, fishing has been one of the important sources of livelihood in South Asia countries, and in India, fisheries contribute approximately a significant sum of 1.3% to the nation's Gross Domestic Product (GDP) (Patnaik and Baral 2012). So, the island livelihoods pattern has witnessed both forms of vulnerability due to changing climatic condition and communities engaged in these livelihood practices has undergone shift in the last few decades on the island.

2.2 Mising Identity in Perishing Island

Majuli boasts of multiplicity of ethnic tribes, and Mising are the largest group among the tribes' constituting 44% of the total population of Majuli and as per 2011 census they are the second largest tribal community in Assam with a population of 7 lakhs. Ethnically, the Misings belong to the Tibeto-Burma clan and they are part of tribal/Adivasi clan of Arunachal Pradesh Miyongs, Padams and Nishis, etc. Mising community has emigrated from the hills of Arunachal Pradesh towards

Assam from the early thirteenth century which continued until the first half of nineteenth century soon the Ahoms[5] established their kingdom in the Brahmaputra valley which still this continues till date as well. They were previously identified as '*Miri*' by the colonizers/colonial state. Mising community predominantly are settled in the eastern parts of Assam (viz., Dhemaji, Lakhimpur, Majuli, Tinsukia, Golaghat district, etc.) and along the riverbanks (near the floodplains) of the Brahmaputra and its tributaries, especially in the northern bank of the river and population residing in the southern bank of the Brahmaputra or in Arunachal Pradesh which shares its border with Assam as well (Pegu 2019). There are many folktales and stories about the Mising community movement or emigration from the foothills to the plains one such story which is tittle '*Story of Tusig Matsig*', which mentions the community being adventurous in nature and they surveyed for new region. But there has been an ongoing debate around whether if it was Tusig Matsig or Ranu Raku, who are really the first person to do so (Taid 2016).

Mising community has their own religious practices and customs and they worship the nature and most of their festivals are interlinked with harvesting festival. Though they follow '*Donyi Polo*'[6] which means (the Sun and moon god) and they believe in the existence supernatural powers of the gods. However, the community have endured through the process of alteration in the Brahmaputra valley. Like many Indigenous communities from Northeast (Rabha, Karbi, Jamatia, etc.) Mising are also nature worshiping community, whose practices and rituals are derived from nature. The community doesn't have a manuscript in particular rather they have a rich oral tradition like folklore, myths, songs, chants, etc. The community largely believed that they received these knowledges from the god of knowledge which they call *Do-ying Ba-bu*, who instructed the community to preserve this by documenting the knowledge base in the bark of tress. However, the elders and commune documented these on the deer skin which was preserved for many years. But when the famine struck in the community it led into the community eating all the fowl which the community owned and after which when the community members didn't have anything to eat. Most of them were hungry and also craving for meat as well, which is when the custodian of the deer skin on which had script written were roasted and eaten, which lead to Mising losing their script.[7] This narrative of the Mising eating their script is quite similar to what (James 2009) documented about the other South Asian communities (Akha,

[5] Ahom or Tai-Ahoms belongs to the Shan family of the great Tai or part of Thai family from South Asia, who ruled then Ahom kingdom present day Assam for almost 598 years. The dynasty was established by the Chaolung Sukapha, who was a Shan prince who believed to have come to Assam crossing the Patkai range in upper Assam.

[6] The community regards Do: nyi-Po:lo as their ancestors and Moon being their Father and the Sun as their mother. In most of the ritualistic performance, they community first recite the name of Ane Do: nyi (mother Sun) and Abu po: lo (father Moon).

[7] As per the folklore and stories shared by the elders from the community, there were many versions of the same story, but often the narratives shared by the community can be seen as something. Wherein, the deer is regarded as pig as the community has been rearing and eating it a long time, and secondly, the famine is often believed by the community as Flood. But still like many others communities from Northeast in which they lost their script which was preserved by the community but later consumed.

the Lahu, Wa and the Karen) who also wrote on such animal hide which was later consumed by them during the deluge or cope from it. Mising community believes in the existence of various transcendental or spiritual lives and actualities which will haunt the community who believes in its existence and who can bring fortune and harm both to the community as well. As per the field data collected in course of 2 years shows that these mystical actualities appear into quaternary classifications, namely. i. ***Uyu*** or ***Ui*** (which is customarily maleficent spirits which dwells into living and non-living beings e.g., river, stream water bodies and also in water, woods, skies, etc., which are efficient in affecting prodigious detrimental or loss that includes substantial destruction and damage, etc.), ii. ***Urom po-sum*** (the levitating souls or spirits of deceased, that might produce ailment or any other detrimental ailments however, the community believes them as their protector) iii. ***Guhmeen-Sohing*** (benignant lineal spirits of the family) in conclusion, iv. ***Epom-yapom*** (are basically the spirits which dwells into tall and giant trees which are usually not damaging, however there were folklores which mentioned that there were times when residents from the community were captured and sometime some forms physical and mental harm were caused and later, they were released or sometime those people were taken to '*Miboo*' or priest for healing). In the Mising community most of the ancestral spirits and supernatural being are appeased by different types of votive offerings which are being made to the deities (which are generally domesticated animals, fowls, etc., from the household or community) barring only ***Epom-yapom*** (Pegu 2019) these practices are done specifically during illness and disaster in particular. Furthermore, time to time the community also appeases and prayed and different forms of offerings are being made to the munificent custodian souls or spirit for the welfare and well-being of households and sometime of the community as well. Even the community deity thunder god is appeased every now and then in order to protect them from his wrath. Mising cultural and ritualistic performances are in link with the nature or ecology in general and most of the festivals are also related to harvest, nature and praying the specific deity to safeguard the family from unforeseen losses, etc., especially during floods in Majuli context.

Apart from these Mising community also worships the spirits which causes lightning and rumbling which are known as (Mukling Teleng), water and earth known as (Among Asi), fire and air known as (Esar and Emi). Based on communities' traditional beliefs system these deities and spirits are their compassionate and generous protector of their family and farms from floods, misfortune, provider of food stocks, etc. As mentioned by the elders and traditional healers.

> We have to appease all these spirits which exist in living and non-living being and some time in order to do so we sacrifice animals which is called as Taleng Uie and Rokpu Done (which translate into eater of white cock). However, as mentioned by him there are other evil spirits as well which afflicts the community too like Asi Uie, Adi Uie Umrang uie which are all related to natural calamities.[8]

Some of the distinct features or key areas near the locale of the Mising village which I observed during the course of my field work was that, most of the household

[8] Excerpts from interview conducted with the Traditional healer '*Miboo*' of Jengrai Gaon (village).

were either located near the river or ponds as their livelihood and dietary practices includes fish, or their house being close to the forest (chapori) which provides the community firewood, medicinal herbs, vegetables to cure small ailments, fruits like Ceylon Olives (Jolphai), Gooseberries (Aamlokhi), Starfruits (Kordoi), Fiddlehead ferns (Dhekia), Green Amarnath (Khutura), Bamboo shoot (baah goj), etc., which are important source of their diet and existence of these sources enables the community to be self-sufficient as well. The community also have been primarily engaged in the riverine activities, animals' husbandry, etc., and the occupation based in the most of the char and chapori (which are river-island or mid-channel bars) formed by the river. Most of these areas were considered as 'wasteland' during Ahoms or colonial period and the geographical position and lack of transportation also made these areas inaccessible to rest of the Assam. Hence, the community particulars Misings and others have become excellent fishermen and boat makers during Ahoms or even during colonist epoch. While at the same time Mising and other community residing in these areas are continued to be one of the most improvised communities being displaces year after year, lack of land, etc., during these reigns (Goswami 2010).

3 Knowledge Base Practices to Cope from Floods

The past and ongoing degradation of environment has been largely through western development which unfits for the local context (Bodley 2008; Broad and Cavanagh 1993) which alienates the IK and practices positioning the connotation that growth and burgeoning simply can transpire with the application of more Eurocentric worldview, scholarship and expertise's and while doing so it completely discards what local wisdom and knowledge base has to offer (Briggs 2005). Like for instance in agriculture so called 'technological solution' often intends towards modernizing the Indigenous method of agriculture as identifying these are old or colloquial and overlooks the prevailing skills, competencies of aboriginals in order to manage their agriculture problems (Biggelaar 1991). In reference to the natural resource management technological management or technocratic management practices has failed to address the sustainability of IK and wisdoms in conservational and management practices of protecting these sacred groves and forest, etc. (Menzies 2006). Similarly in Disaster Risk Reduction which follows a more top-down approach often miss out to integrate Indigenous voices or their capacities, participation in planning and response during disasters as well (Dekens 2007; Mercer et al. 2008). Traditional knowledge and practices have the potential to act as a mean of coping from disasters and showcase to the global community to decide the utmost efficient and resourceful approach in order to endure the consistent and anticipated production of resources which are meant for sustenance, survival and also towards a more sustainable approach for procuring and utilization of community owned resources. However, it is vital to pass on these knowledge base and wisdoms which are limited to certain age group, section of people to the youth and new generations through their participation in conservation practices, stories, songs, chants, folklores, etc., not only for preparing the community from deluge but also sustenance of these practices for long run. IK systems stipulate the foundation for the decision-making power at the community level as well especially. In areas like healthcare, agricultural practices, food preparation and most importantly in natural resource management. Since, most of these practices are developed and adapted through various local ways of thinking and doing. The knowledge base practices of Mising are used largely used to prepare from everyday precarities and to reduce its impacts. The Mising communities have mastered these over the years and they have started living in consonance with nature and their traditional wisdom helps them to detect and identify the possible hazards or disasters.

The coping mechanism developed by Mising were based on their folklore or stories which are passed generation to generation orally to one another that were useful in understanding nature and the causes of disasters. Most of these practices are known by the elders of the community, women who takes the responsibility of not only preserving but also transmitting the knowledge base to another as well. These practices over the years have helped them to identify the indicators which aid in predicting disasters, as well as ways and means of mitigating the effect of floods and erosions.

> We have our own flood predictions techniques and we observe sets of early warning sign which help us to predict the intensity of flood. Like the soil sediments coming downstream from which we get an idea of how heavy the rains would be. If soil sediments are flowing in the river before the onset of monsoon, it signals that flood will come and the rain would be heavy leading to floods.[9]

The house structures, food storing practices before the deluge, rescue boats are central for the community residing in the island and primarily for Misings. The traditional Chang Ghars (stilt house) is the traditional housing structure of the Mising community. It has been observed that people from other commune in the isle have started adapting Mising housing structures to save their life and valuable assets from floods. There are certain Indigenous practices which are used by the community to mitigate the impacts of deluge in the island which are discussed below and these strategies (Indigenous Knowledge) used to prepare from floods are based on the principle listed below.

3.1 Existence

The process of understanding the coping and adaptation mechanism of Mising community from floods has to be looked from the lens of how '*nature*', '*animals*' have been embedded in the Indigenous '*culture*', '*belief system*', '*faith*' and tradition, etc. Also, how these practices have evolved over the years inculcating new Indigenous methodologies or scientific knowledge for not only preparing from floods but as a coping mechanism during the deluge. Like many other Indigenous communities from Northeast India, Mising too had a strong belief system. Folklore is centred

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[9] Excerpt from interviews conducted in gram panchayat of Bessamora Gaon, Majuli.

around existence of ‘Good’ and ‘Evil’ spirits where the first one is believed to be their ancestral spirits whom they call every year to seek their blessings, while the later brings agony or trouble to the community (Pegu 2020). Some of these spirits also exist in the nature (like in the forest, rivers, hillocks or even skies, etc.) which are appeased through different ritualistic performances and offerings like fowls and other animals too. There are numerous stories in the community which shows their co-existence of the community with nature or animals too, according to the stories about how Dolphins were created. TGhe community believes that dolphins originated[10] from Mising Women who were unhappy with the family members as they were forced to marry someone against their wish. So as the girl was anxious by this she jumped into the river and took her life, many believes that she was later transformed into dolphins. This method of ‘co-existence’ or ‘living with flood’ has been the key source of their sustenance and survival from perennial flooding as the communities focuses more on preparing or coping mechanism rather than trying to contest with deluge. So, through the course my field work and engagement with the community, I as a researcher observed how these traditional ecological knowledges gets exhibited in the daily engagement, conducts, etc., starting from their housing pattern, agriculture practices, preservation and storing practices or how the villages are being organized, etc.

Mising communities’ capacity toward acquiring the reservoir needed for subsistence in usual environments doesn’t differ or gotten transformed gradually or it didn’t go through periodic forms of expectable transformation, unlike weather or season throughout the year, etc. The community uses key strategies based out of the local knowledge system viz. creating shelters on higher grounds, making stilt house, stocking food items before the onset of flood, repairing of houses and boats, etc., has been prerequisite of the community to cope from the deluge year after year.

3.1.1 Housing Patterns/Structure

Mising communities mostly resides and positions near the riverbanks or near any watercourse and their houses can be notable due to its distinctive stretched residence which are known as Kare Okum in Mising language (in Assamese they are called as Chang Ghar) that are constructed either on raised bamboo or cemented pillars/stand that are usually elevated approximately six feet above ground which are mostly made of wooden posts (Figs. 1 and 2). These houses due to its distinctive architecture and being built on raised platform are highly adaptive towards the recurrent floods the state receives. Over the years other communities have also started adapting this type of the housing patters. People residing near the Brahmaputra, build Chang Ghar so that the water can easily move under it without affecting it and also keep wild animals

[10] Although the original story is titled as *The Porpoise and the Crocodile*, this is highly likely that the porpoise mentioned in the story probably means the endangered freshwater Gangetic Dolphins which are seen in both the Ganges and the Brahmaputra River basins as porpoise are usually not found in Indian sub-continent.

Fig. 1 Chang Ghar (stilt house) traditional Mising house

Fig. 2 Mising household with brick pillars

at bay too. While people residing far from the river make these types of houses for temporary shelter during floods.

The Chang Ghar or stilt house which are primarily constructed with bamboo are significant part of the cultural identity of Mising community which is also a native adaptation and protection technique in order to cope from the deluge which are driven by observing the local environment and climatic condition. These housing pattern which are constructed on raised platform are exceedingly adapted for the recurrent flood that a large part of districts located in upper Assam and specifically riverine areas receives. Kare Okum (Change Ghar/Stilt house) built by Mising is one of the significant parts of their vernacular architecture which showcases the traditional built keeping a distinct environment from region in mind. The roof, porch and floor each serves as a distinct feature not only during normal times but also during floods. The kitchen of the Mising is quite distinct in its resemblance like as most of these houses have bamboo/Wooden flooring above the bamboo silt platform which is why the fireplace are made above the floor, which is called as '*Meram*'. Every household will have two separate shelves made of bamboo, called as '*Perab*', '*Rabbong*' or '*Rapte*', '*Kumbang*' and '*Koktok*' (storage for utensils pots, etc.) which are hung right above the kitchen space and both of these shelves are tied with ceiling of the house using the bamboo poles, jute or coconut ropes (Pegu 2020). These two shelves play significant roles in preservation, smoking and storing different food and meat items. Perab which is right above fire, is usually used to smoke meat (pork, goat) or fish, etc., are preserved which can be eaten even after year or so especially during the floods. The community chooses to preserve only certain meat because the communities are traditionally engaged in livestock rearing or fishing as they live closer to riverbanks or ponds, etc. Just above the Perab, there is a Rabbong or Rapte where they place all the pots that are usually filled with rice beer mix which are store for fermentation (it is filtered as the need in the family or for rituals or festivals) or rice and firewood, etc., are kept for use. Above Rabbong or Rapte is ceiling layer of the house which is called as '*Kumbang*'. It is the gap between the roof and '*Kumbang*' where vegetables like bottle gourd, pumpkin, garlic, onion, etc., procured from farms or kitchen gardens are usually stored to prepare themselves for onset of the flood. Most of the food items kept above Meram are usually free of bacteria and fungus and it can be preserved for longer duration due to smoke which comes out the fireplace while on the other hand thatched roof (made of haystack) provides the cooling effect and saves it from getting spoilt easily. Apart from these Mising households there is another distinct attribute which aids to cope from the deluge and it is the presence of huge verandah or front porch in the house called '*Tunggeng*' (Pegu 2020) or '*Yapkur*' (backside verandah) both of these usually have quite larger space. During disasters these spaces are important sources of survival as the house located in low elevation like Assamese communities who doesn't necessarily make Chang Ghars, when their house gets inundated due to floods, they or the livestock of the community also takes refuges in '*Tunggeng*' or '*Yapkur*'. Even the graineris (high rise platforms) or the '*Yegom*' (pig stays, duckary, etc.) which are built follow these structures (stilt) that keeps the livestock and food safe during floods. The community house where most of the rituals, community functions and meetings take places called as '*Murong Okum*' are also built-in high-rise platform too as the elevation of this place is higher than the house, even if the houses get inundated, people can take refugees in this during floods. So, keeping all these in mind and importance of vernacular architecture in mind which safeguards people lives during the deluge even now these platforms are being constructed in flood affected villages in Assam under the MNREGA schemes as well. The lasting reproduction of the colonial intervention can be seen in the tea gardens from Upper Assam and how the houses of '*Babu*'*s*' (managers)/or the government officials house were converted into '*Chang*' bungalows which had manicured gardens and with a view of the tea gardens. In the post-colonial times a large number of these bungalows were converted either into luxuries home-stays, resorts, hotels which is nothing but the colonizers appropriation of Indigenous architectural marvels Kare Okum (Chang Ghar/Stilt house) built by the Misings. Apart from traditional Chang Gahr (Kare Okum) one of the prominent architectures that is prevalent in Assam is Ikra/Ekra construction which is called as Assam type home/construction. These typologies are quite common in other north-eastern states as well. Usually, it is constructed with bamboos, mud, thatch, wooden planks, etc., though the use of material varies based on the economic status and income of the household however, in other cases even concrete construction is also common in these types of construction as well. In the research area, bamboo made Assam types house were common as the district has abundance of Bamboos and as community has the most middle-income group, for them building Pucca house is not feasible and lack of accessibility or financial resources is the reason why they use local material like bamboos, woods, etc., for construction of houses in the isle (Figs. 3, 4, 5, 6, 7, 8 and 9).

Fig. 3 Meram

Fig. 4 Porag (1st) and Rebbang

Fig. 5 Kebbang

Fig. 6 Tunggeng

Fig. 7 Yapkur

Fig. 8 Yengom

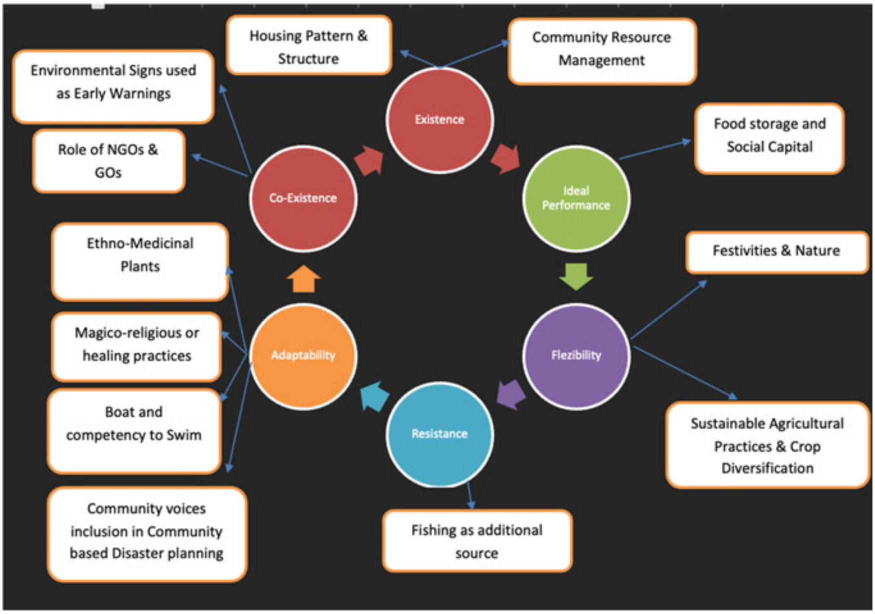

Fig. 9 Principle of Mising indigenous knowledge system for disasters

3.2 Deluge and Ideal Enactment/performance

Indigenous or local communities has capacity in order to make the ideal use of the scarce resources easily available in the ecosystem. Communities residing in such environments has developed strategies or mechanism which are characterized as ideal enactment or performance viz. the community based on their local knowledge system have designed highly effective means of using optimal and scarce resources can be characterized through ideal performance, i.e., by developing highly efficient means of using scarce resources which varies from taking a stockpile of resources

Fig. 10 Granaries for storing rice, vegetable, and sugar for floods

before the onset of disasters, storage of food grains, dwindling fish stocks due to building of embankments, to limited time availability, etc.

3.2.1 Storage of Food Grains

Majority of the Mising families before the onset of deluge stockpiles additional food grain (rice, lentlis, sugar, jaggery, tea, vegetable which can last longer, etc.), livestock, medicines for fever, headache, nausea, etc., and cash which the community can draw especially during deluge or post-monsoon, this is the community relied on during deluge. However, the stored food or items being stockpiles varies to family to family depending on the socio-economic position (Fig. 10).

> As you all know that Majuli is perennially affected by flood throughout the year we store food grains like rice, lentils, salt, sugar, jaggery, oil and vegetables like pumpkin, bottle gourd, Xukan Maas (dried fish) etc. along with other necessary thing for floods and this in a way helps us to survive for few days during the floods as it takes almost 4-5 days sometime even week to get aid from government and non-government agency.[11]

3.3 Flexibility

Mising commune based on the lived experiences with disasters has designed adaptable mechanism and methods so that community can utilize the community owned resources or reserves which can be used during deluge, on the other hand also having

[11] Excerpts from interview conducted with residents of Salmora village.

reserves of alternate or addon resources which can be utilized when reserves of some resources vanishes or disappear. The community adopts method of planting variety of crops (primarily different rice variant) as per season, vegetables, species, adopting variety of livelihood mechanism which can withstand the impact of flood or use it as a coping mechanism during disasters. This clearly depicts how local communities has used their knowledge based to cope and withstand the variation in the environment some of these practices are discussed below;

3.3.1 Agricultural Practices

Agriculture is considered to be significant means of survival for Mising and others as well in Majuli. This is not only done for the profit or for livelihood but it also provides the means of sustenance which is stored for floods which aid in reducing the impact of flood on the commune. However, the rate of agriculture production and development has been dwindling because of perineal flooding riverbank erosion, absence of suitable prerequisite during winter for cultivation, small landholding due to rampant landlessness emerged from erosion. The Mising community has mastered their agricultural practices as per the local condition and started growing paddy (rice) which are suitable or can withstand the impact of floods. The community apart from growing traditional '*Lai Aam*' (aam-rice) adapted different varieties of rice which requires less water that can be harvested before or post-flood situation as well. While migration of the community received low intensity of flood, the community adapted '*Aamdang Arig*' (wet paddy cultivation). Adapting these variety of rice aid the community to optimally use their cattle's for ploughing and managing a consistence supply for rice in the household (Pegu 2020). In Mising community cultivation of *Ahu* occupies a central place and is also related to their major harvesting festival which is discussed in the later section of the paper.

> We grow Saali rice in high line areas and deep-water rice (Bao/Bau Rice) is grown in water flooded and low line areas. The deep-water rice is not affected by flood waters and can be harvested after the floods recede.[12]

This kind of rice can withstand the impact of deluge and these variety can be harvested without being worried about the produce. Also, that is because the Mising doesn't waste there farming produces due to recurrent floods in the state. The deep-water rice which are cultivated by the community also doesn't get impacted due to inundation and the paddy can be harvested when the water level recedes as well which shows the variety of agriculture produce the community has adopted to minimize the impact of the disasters.

> They also mentioned that specific variety of rice like 'Bao' which easily grows in the water-logged and marshy areas; can also withstand strong currents as well. Hence, the communities as their flood resilient agriculture practice mixing of two varieties of rice 'Bao' and 'Ahu' in order to ensure atleast one crop would possibly sustain the floods. Also, he mentioned the

[12] Excerpts from interviews conducted with the farmers in Moulal Kalita.

famer also grows 'Boro' another variety of rice which is suitable for the island as it ensures food security for the community.[13]

The central predicament faced by the Mising agriculturalists in the isle is due to soil erosion and sand accumulation in their farmland post-receding of flood waters which impact the farming practices at the same time due to the recurrent flood a sizeable portion of lands are also lost to the mighty the Brahmaputra year after year. That also leads to impact the age-old framing practices and some impacts productions of some agriculture produce are being lost by the community due to this process of riverbank erosion.

3.3.2 Festivities and Nature

If we look at the festivities of Assamese or Mising community there is symbiotic inter relationship between their festivals and nature. Bihu (harvest festival) and Ali Aye Ligang[14] (celebrated by Mising) the festivities which marks the commencement of agricultural season in Mising commune only after the festival and they begin seed sowing of particular variety of rice i.e., Ahu dhan.[15] If we gaze at the festival closely it shows their closeness with nature as well with their ancestral spirits which are believed to be the protector of the community. The festival marks the existence of remembering through a ritualistic performance '*Juri*' wherein the communities call upon their ancestral spirits or ancestor and offering like '*Purang apin*',[16] or '*Poro apong*' or '*Nogin apong*'[17] are being made and they asked them to protects their harvest and pray for good harvest so that the rice stock could feed the family.

If we look that the Ali-Ai-Liang through cultural repertoire we may see that the festival celebrates community's closeness with nature and in Mising community through the ritualistic performances which is known as '*Pakso Moran*'[18] where the community sprinkle the '*Ahu*' dhaan (paddy) in the fields and during the performance the other members of the family or community joins irrespective of their age to perform in the event. Their closeness with nature biota is also reflected in their traditional dance like '*Gumrang*' and songs as well which has great socio-cultural significance in the community. Similarly, there are other festivals which

[13] Excerpts from the interview conducted with the farmers in Moulal Kalita.

[14] The literal meaning of the words, Ali translated to *legumes*; Aye signifies *seed* and Ligang *to sow*. This is spring festival celebrated in the month of Fagun (which corresponds to February and March as per the Gregorian Calendar) in the first Wednesday of the month. In this festival, the community worships mother earth for good production of Ahu paddy (rice).

[15] Local varieties of rice grown in Assam.

[16] This is nothing but boiled rice which is wrapped in leaves which the traditional Assamese people call it as '*Tupula bhaat*', the literal mean of which is rice cooked in leaves.

[17] These are traditional home-made rice beers which are unique to the community and mostly available in most of the Mishing/Mising households which is offered to the people during any festivals/rituals or when someone visits their homes.

[18] The dance form is performed in order to appease the ancestral spirits, deities or divine power who will bestow their paddy cultivation and which can feed the family.

clearly signifies their interdependence with nature and close linkage with harvesting '*Porag*' which is another festival celebrated while cultivation of a particular variety of rice i.e., Ahu rice, for which Morung (traditional dormitory) in most cases newly made and decorated after which the '*Miboo/Mibus*'[19] from the community is called to perform the rituals and he who makes contact with the spirits to protect their harvest. The festivities start with makes offering to them and which last for three to four days with feast and dance performance in continuity.

3.4 Resistance

It is mechanism to cope from momentary unpredictability in the ecology which occurs in the community which can be irregular inundation or droughts, deficiencies, etc. In such conditions the community living in these geographies devise a mechanism or method of resistance or approaches in order to endure these transitory variations brought by internal or external changes in the environment. By adopting different means like storing certain resources which can be food reserves, capitals, savings, medicines or relying on their customary approaches of survival are specimens of community owned surviving or coping mechanism from the unpredictability in the ecosystem.

3.4.1 Fish as Supplement Source of Food

One of the imperative sources of Majuli economy has been Fish rearing and fishing and people belonging to Schedule caste and Schedule tribe community are engaged in these practices since ages (Das 2017). However, fish is one significant source of diet not only among Mising or tribal communities but also among the Vaishnavities as well. In traditional Assamese society as well as Mising communities fishing has been a common thing and largely Mising community uses *Zurki*, *Chaloni* (Sieve), *Diradang* and *Porang*[20] are some of the most common instruments being used by them as well other some non-tribals communities from and non-tribals. However, with time people from the field are largely found to be using fishing nets for fish catching. At the same time due to creation of embankment and encroachment of wetlands fishes has gradually reduced in number.

Fish become an important source of sustenance during floods as well. One of the common food items preserved by the community is in the form of dried fish called as *Ngo San* which is sun dried fish and can be eaten after months and during the time of floods these are used by the people to sustain.

[19] They are traditional Mising shamans or priests/seer of the community who are called whenever someone falls sick or anything bad omen happens in the family they are called to detect the evil spirits which is responsible for this and they suggest the rituals to the community.

[20] These are some traditional instruments used to catch/trap fish in Assam.

> She mentioned Mising community has its own preparedness plan, we live near the water sources hence our dietary habits include fish and it is also an important source of livelihood for us. So, whatever the surplus fish that we catch every year the women of the household sundried those fish which is call as "Xukan Maas (dried fish) and it is preserve for the floods along with other food grains like (Rice, Dal, Pumpkin, Sugar, Tea etc.) for flood which helps us to sustain for few days if the aid/relief takes time to reach us.[21]

3.5 Community Adaptability/Adaptableness

Communities capacity to transform their practices to endure from foremost and lasting variation in the ecosystem were based on their experience from the past in order to produce a distinctive ecosystem which is by adopting the best strategy by the community with time to adapt themselves from floods by devising new and also integrating age-old practices with new one primarily with technocratic and scientific techniques, also by espousing pioneering means of dealing with the diverse environments. Example 'using the ethno-medicinal, adopting new forms of communication or transportation, use of community radio or radio for early warning from floods are examples of coping strategies'.

3.5.1 Ethno-Medicinal Plants Used During Floods

The Mising community has been practicing plant-based healing practices during floods to cure their health problems and they believe that these are very effective. The community firmly believe that information of the plant medicines should be kept secret or protect otherwise it would be losing its efficacy which is why they do not like to reveal this information. Mising community has mastered over the traditional method of healing practices used by the community to treat and heal different health ailments by applying different ethno-medicinal plants, herbs, etc., that are used in different forms like freshly made drugs, juice which are used as oral intakes and also some of the ethno-medicinal plants are applied on the skins as well for various diseases. They use the locally available medicinal herbs to cure such ailments. Some of the traditional plants used during the floods are as follows (Table 1).

The communities worship their ancestral spirits through different rituals which are namely Dobur Uie,[22] Dod-gang[23] *and* 'Urom Apin',[24] etc., and they consider

[21] Excerpts from the interview conducted in Bebejiya Gaon.

[22] That's the principal or central ritualistic production of Mising and it is performed for people who have died relating to sinful death or incidents (Pegu and Gogoi 2021).

[23] These rituals are also performed after the demise of anyone in the family as the community opines that the souls of people don't lose or forget all the mundane desires easily, which is why these rituals are performed to fulfill their desire before the soul departs from earth towards eternity (Pegu and Gogoi 2021).

[24] If anyone dies in the Mising community they perform this ritual for the departed souls which is known as—Urom Appin within a time frame of a month or so (Pegu and Gogoi 2021).

Table 1 Mising and their use of Ethno-medicinal herbs for curing ailments

Scientific name	Native name	Parts used	Disease	Methodology
Pongamia pinnata (L.) Pierre Fabaceae	Karanj (Pongame oiltree)	Leaf	Urinary infections or issue	The juice extracted from the karani leafs are consumed to cure this
Ricinus communis L. Euphobiaceae	Erapat (*Ricinus communis*)	Leaf	Stomach pain	The leaf of erapat are pounded in pasel and mortar and then applied on the areas which has pain
Scaparia dulcis L. Scrophulariaceae	Mithasem (*Scoparia dulcis*)	Leaf	Used for digestion, fever and aches and pains	The juices from the leaf are extracted and consumed and, in some cases, leaf are used to make a paste which are applied in the area where the pain is for getting relief
Saccharum officinarum L. *Cheilocostus speciosus* *Averrhoa carambola* L. *Carica papaya* L.	Kuhiya (sugarcane) Jam-lakhuti (crepe ginger) Kordoi (star fruits) Amita (raw Papaya)	Stem juice	Jaundice	Juice to cure Jaundice taken orally for few weeks to cure jaundice
Punica granatum L. *Houttuynia cordata* Thunb *Ocimum americanum* *Phylanthus niruri*	Dalim (pomegranate) Masandri Bon (wild) Tulsi (basil) Bon Amlokkhi (wild gooseberry)	Paste of tender leaves Smoked young areal parts Seeds Fruit	Dysentery	Eaten raw twice a day It is usually eaten twice or thrice in single day Five or six times in a day
Citrus aurantifolia	Lemon/key lime	Juice and extracts	Fever	Lime juices are mixed with sugar and applied on forehand 3–4 times
Acoraceae/*Acorus calamus* L. *Hedyotis lineate*	Boch (sweet flag) Kasidoia	Decoction of roots Juice and extracts with water is drunk	Pneumonia	Orally taken twice a day
Capsella larsa pastoris *Piper longum*	Gonga Moola (Brassicaceae) Long pepper	Seed Seed mixed with Misri	Diarrhoea	Orally drink 3–4 times in a day

(continued)

Table 1 (continued)

Scientific name	Native name	Parts used	Disease	Methodology
Xanthium strumarium	Agora (Clotbur)	Roots or leafs	Malaria	For 20–25 days or till the fever is down

it to prevent the performances community from health ailments (Mipun 1993). In order to do so they perform certain practices and traditional healing practices and also perform certain ritualistic performance to cure diseases, however, due to the influence of Vaishnavism on the community, it went major Sanskritization of community which has led to change in their practices.

3.5.2 Magico-Religious or Healing Practices

The healing practices among the forest dwellers particularly Mising are not only confined to procurement of forest-based resources or for preparation of ethno-medicines or folk medicines but at the same time forest are also seen living entity with transcendental manifestation for the community. Apart from using these folk medicines the Mising community cures health ailments through different magico-medicinal or magico-religious practices which depict community's propinquity with nature and reverence of not only the scared forest/groves but also the spirits living within that.

The member of the community offer prayers and animal scarifies which are common site to appease the supernatural beings or certain spirits which are said to be the cause of different disease and even death in the community. As mentioned by the elders from the Jengrai village.

> In our community mainly any kinds of ailments or deaths occur mainly due to four reasons, i) Anger of traditional/ancestral gods (wrong propitiation offered to the deities or ancestral spirits) lead to various disease. ii) Anger caused to the ancestral spirits by anyone from community. iii) possession of bad spirits by people (he mentioned that these evils spirits which are possessed by people to harm other and they leave these spirits on others if they have personal enmity between themselves, which leads to different diseases, health ailments, irrational behaviour and sometime losing mental stability etc.) iv) Breach of social taboos meant for the community member like:

a. Like eating meat of cow and elephant as buffalo are used in agriculture and elephants are considered of having spirits.
b. If men from any household have copulation with a menstruating woman, then such men are considered to be impure or polluted by the people.
c. If someone walks over the cow tether especially if it is crossed by pregnant women, then it is believed that the life expectancy of both mother and child is reduced.

d. Entry of pregnant women in crop field, kitchen, or sacred sites are seen bad omen, they believe if a woman enters crop field it destroys or harm the crop or yield.[25]

So, if these taboos or anger of gods, ancestral spirits lead to different ailments like chicken pox, irrational behaviour, insomnia, mental disorder, deformity on births or limbs, impotency or barrenness, etc., among the community. Most of these diseases are caused due to violations of taboos, wrath of ancestral deities/spirits, effect of evil spirits and most of being supernatural origin. The community believes that these ailments can't be cured by the allopathic medicines instead they can be treated through magico-religious therapy done by the 'Miboo/Bej' (who are faith healers. Through performance of some magical rites and rituals, by making offering in their prayer hall[26] or by animal sacrifice or by appeasement of the deities or driving away the evils spirits from the body they cure the person afflicted due to that. The community shares a cordial and alienable relationship with ancestral spirits and deities which ensure their good health of their families. As mentioned by the of village elders from Mising Chapori and Bebejiya in Majuli.

> Every year the head priest 'Miboo' performs different religious ceremonies during the annual festivals in order to restore their relationship with our deities and spirits to ensure the protection of the families and keeping the faith in these practices among the young generation, which have gone through a major Sanskritization and adopted vegetarianism and transformed from Tribalism to Hinduism (adopting death rituals, religious function as per Vaishnavism or praying in Namghar[27] which are built by Vaishnavities saint as mentioned by Robert Redfield in little to great tradition, about the transformation of the indigenous practices due to the influence by the greater tradition like Vaishnavism into Donyi Polo practices followed by the Mising[28].

The community also believes that if these ancestral spirits are not satisfied and bad omen are committed by them then they can inflict disease on the community and sometimes on the community as well. In this section I will be discussing Mising communities strategic magico-religious or healing practices performed by them:

The community believes that evil spirits are supernatural powers which are malevolent which doesn't harm anyone without provocation and the pregnant women and children are primarily vulnerable towards these. The community believes that any unnatural or untimely deaths of people whose wishes were unfulfilled at the time of death their spirits tend to hover, death due to suicide, trampled by evil spirits, etc., these become evil spirits and which may harm the people. However, these can be averted by '*Miboo*' by performing certain religious practices and sometime they give Talisman which has some magical powers are helpful in preventing these attacks on people.

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[25] Excerpts from field notes collected from elderly men from Jengrai Gaon.

[26] Namghar is prayer hall of Vaishnavites, however, with the the tribals converting into Vaishnavism can be regarded as Sankritisation as M. N. Srinivasan.

[27] Prayer House which was introduced by Vaishnavite saints Shrimanta Shankara, Madhavdev who also tried to eliminate the caste and creed-based discrimination through education.

[28] Excerpts from interview conducted in Bebejiya Gaon.

They believed that there are spirits like ‘*Yumrang Uie*’ which lives in forest and it is omnipotent and omnipresent ‘*Taleng Uie*’ and (souls or spirits that resides over Earth), ‘*Asi Uie*’ (souls or spirits that represent water bodies or resides in these bodies) or so on. So, if these spirits are unhappy with the acts of people it can inflict some problems which are detected by the ‘*Miboo*’. The community derives their deities and gods either from nature or ancestral spirits but until the community came in contact with Assamese and other communities from the plains of Assam. Unlike any other community they also went through a process of Sankritization or Hindusation process in terms of following religious practices or worshiping deities like ‘*Satjanta*’ ‘*Jalkai*’ *Ghar Dangaria*’ (Festivals for dead forefather) ‘*Aipuja*’, etc. (Das 1981), which are completely alien or not traditional to the community in general. Rather these practices were believed to be borrowed from non-Mising Assamese communities. The first religious conversion of the Mising could be traced with Paramananda (Mising person whose name might would have been different from before the conversion) which was started with Sankaradeva (1449–1569), who is the founder of neo-Vaishnavism in Assam have converted him to Vaishnavism faith and must have renamed him as Paramananda, which means the supreme pleasure.[29]

The community is traditional worshippers of spirits related to the forest, thunder, water and river, etc. But at the same time community also opines that there are several additional malevolent soul or spirits like *Umrang Uie*, *Asi Uie* or *Adi Uie,* etc., which afflicts natural catastrophes and diseases. Traditional belief system of the community is that the world or cosmos are created by two divine energy which is known as ‘*Sedi Ba:bu*’ (The Father and ‘*Melo Nanc*’ (The Mother) which are considered as the descendants of Sun and Moon. These spirits are omnipotent, omnipresent and they have been always compassionate and generous towards the community. That is why often the community first offers prayers to these deities before the start of any social or religious functions in the community (Das and Doley 1995). The customary faith and magico-religious rituals and ethno-medicinal/practices inhabits imperative position in the health care practices of Mising community unlike other Indigenous community from Northeast India; who also opines that malevolent soul and spirits are responsible for afflicting various diseases on the community. Hence, the community perform numerous religious ceremonies and sacraments that are customary among the Mising community which are used by the community to cure different ailments as well. However, due to education, improvement of socio-economic condition and primarily due to awareness to significance health, also due to advent of contemporary medicines, advanced health care facilities, the communities are overlooking the traditional ethno-medicinal practices or being the healers limited the community are becoming more preferential towards allopathic medicines rather the traditional herbal medicine.

[29] Neog M (1965) *Sankaradeva and His Times-Early History of the Vaisnava Faith and Movement in Assam*, p. 369. Gauhati University: LBS Publications (2nd eds.) ISBN-10: 8185921857.

3.5.3 Competency to Swim and Boats Among People (for Rescue and Relief Distribution)

Swimming skill during the disaster also adds to their coping capacity and large number of people in the village relies on their ability to swim during floods. If we go by popular notion that most of the communities living near the riverbank knows swimming. However, the recent movies '*Village Rockstar*' which is based on Assam unfolds a different narrative all together wherein the mother of the adolescent protagonist Dhunu (Banita Das) narrates that how she lost her husband to floods as he didn't know how to swim or he was too timid to learn swimming leads into drowning in the Brahmaputra. While collecting data it was found that most of the tribal and non-tribal community respondents knew swimming as they have grown in the flood geographies (Das 2017).

> One of respondents explains that swimming is one of the main surviving skills in flood geographies of Majuli, she explains that inability to swim during flood geographies not only posed threat to their life but at the same time increases the burden on women and other family members (who knows swimming) to fend for others life in the community. She mentioned that we have spent most of our childhood and adolescent swimming in Brahmaputra and its tributaries and we have learned this from our peers, brother, sisters or mother so that the skill can be learnt to save our lives during disasters.

Besides these majority of the households owns a country made boat which is largely used by them during floods. As explained in the earlier sectmion that Misings are great craftsperson when it came to boat making during Ahom period or even during the colonial or post-colonial times as well. As most of the community resides near water bodies, boat has helped them not only in their daily activities but also in ferrying business too which has been a source of livelihood for the community as reported (Nayak and Panda 2016). But due to re-theorized livelihood practices of the community, logging banned and wood becoming expensive the household who don't have boats have adapted themselves making rafts made from bamboos, wood or in large number of cases make rafts from banana trunks or stems which helps them to save their family during floods. Movies like '*Village Rockstar*' clearly depicts the life and struggle of communities living in area perennially affected by floods and how the protagonist and other characters take out their country made boats not only to save the families stuck in flood but at the same how their family themselves time and again return back to their homes to shift their belonging from one place to another (Das 2017). Similarly in the context of Majuli as well a boat plays a vital role for the people not only for survival from flood but also a mean of generate livelihoods.

> As the island is connected through Brahmaputra River and ferries and boats are the only source of transportation, most of the households have country made boats in their house, if some families don't have boats in their house, they had to make rafts from banana trunks which helps them in order to fend for their family as well to save their family during floods.[30]

[30] Excerpts from the interview conducted with Mising families from Kamalabari Ghat.

3.6 Co-existence

Communities' ability to survive through their Indigenous practices developed by them and also by making coexistence strategies using the IK system and engaging with NGOs and GOs to prepare rescue plan for village, setting up raised toilets and hand pumps for potable water, etc., where the prime work undertaken. Indigenous waring plays substantial role is increasing the resilience mechanism of Indigenous communities. The finding of the research shows that the early warning systems of the Mising community are amalgamation of various forms or methods of techniques and knowledge base that are either survived by the community or passed on through a method which is quite distinct from one another (Howell 2003) (Table 2).

Incorporating technical or methodical knowledge with the traditional way for predicting flood was observed as a '*normal*' process that undertook within the Mising community without much of resistance from the community. One of the key roles that women folks play in disasters is by ensuring food security through storing and preserving different food which are easily accessible to the community. Like preserving and drying fish, vegetables and other food items, etc., using the local methods or practices during winter or time of the year when the state receives less rainfall variety of methods like drying, smoking and other preservation methods are used (using special kind of woods, temperature, spices and salts, etc.) and scientific methods learnt from training provided by government and nongovernment organizations.

Table 2 Early warning systems used by the Mising communities for floods

	Local/native wisdoms and practices	Technocratic knowledge base
Sources	• Understanding or interpretation of early warning signals manifested by nature and animals • Observing the movement and behaviour of insects, animal's birds, etc., to different surfaces before the onset of disasters • By observing the *variations in* the behavioral changes and movements of the animals and migratory bird	• Watching the weather forecasts in (TV, radio, and newsprints) • Usage of information receive from *rainfall measurements automated* weather stations/satellites, etc
Engendered from	• Lived experience with deluge • Through man and nature association • Folklore and Cultural histography	• Outside effects or influences • Through various associations and Institutes at village, block or community level • Migration, displacement and resettlement processes
Conveyed through	• Folklore, stories, chants, songs, stories, etc., which are part of Indigenous daily engagement	• Documented source, visual diagrams, educational campaigns and dialogues among outsiders and the native or locals

4 Environmental Signs Used as Early Warning System for Flood Prediction of Mising

Aboriginal or local knowledge plays a vital role in these vulnerable geographies with limited resources in order to cope from deluge, mitigating its impacts, preparation and saving lives and livestock from perineal flooding. Before any major deluge the nature shows some signs about the possible disasters in the community hence the local communities are able to notice and identify these as they live in consonance with nature. That helps the community to prepare prior to these deluges which aids the community to cope primarily the Indigenous communities have mastered these knowledge base.

> Before the flood the wild animals start to retract to higher grounds and there are significant changes in their behaviour during the last flood our dogs wouldn't stop barking and our cows become restless the night before the flood the signs showed by the animals made us aware about floods are approaching. Besides this, the local information system is quite active during flood season or the rainy season. Regular updates are circulated by radio and ham radios to the villagers about the approaching floods or any unpleasant natural event[31]

4.1 Environment Signs

Flood is expected when it rains for ten to fifteen days continuously and community asserted that by observing the clouds or its roaring sounds of clouds, some elderly predicts the amount of rainfall, etc., especially in village like Halmora which experienced floods every year due to proximity to the Brahmaputra.

> Another warning system that works is observing the rain pattern. If during the beginning of the rainy season, it rains heavily for first week or more than 10 days continuously, it predicts heavy flooding and during such times we evacuate to higher grounds. She also mentioned that Women are important source in keeping this practice alive as they pass on these indigenous knowledge systems orally to their children and other members which helps them to prepare from disasters (experts from Field).

Another way of predicting floods is by observing the soils in the village before the floods as the soil becomes moist and wet, which is when inundation is predicted or it will be coming soon.

Folklore/Folktale (Crop Yields and Fruits)

There is very popular proverb in Assam that if the production of fruits crops brings floods which is way of forecasting floods in these areas. And the abundance of jackfruits gets good harvest for the season. The proverb is

> *Aame aane baan pani, Kothale aane bhoraltot Dhann*

[31] Excerpts from the Interviews conducted with the residents of Kamalabari Ghat.

The translation of the proverb is if there is abundance in growth mangoes in the season which mean it would flood and on other hand if the jackfruit grows more than it would mean good harvest.

Demystifying the folklore/folktales

Communities living in flood geographies are cautious about the disasters and abundant production of certain fruits which are indicators of disasters in these geographies.

4.2 Traditional Belief System: Observing Animal Behaviour to Predict Floods

Mising have mastered in patterns of animal's behaviour before flood and by doing so there were many cases wherein communities have predicted flood and prepared the community. The community predicts rains, flood and other disasters by observing behaviour of the animals, reptiles, birds and even insects as well. Some of the predictions are discussed below:

Folklore/Folktale (Unconventional animal behaviour)

The communities have erudite these practices from observing the pattern of animal's movements, and the unusual sounds made by them which have aided them to predict disasters in the island, these methods are also used by the non-tribal Assamesse community as well.

- Before floods they have observed the snake's starts to roaming around the homestead areas.
- Another unusual way of predicting flood is observing frog as they mentioned that when frog croaks in a unfamiliar way that helps them to predict floods in coming day. In some cases, when frogs' croaks for a month before the onset of floods and they would stop croaking when the flood water rises.
- If dogs howls or cows wails continuously at night it is sign of upcoming flood.
- If pigs start getting restless in their pig sty and start crying at night
- If the rooster, cock and hens climb rooftop of the at night and then starts crowing then that is indication of flood in the following year.

Demystifying the folklore/folktales

The commune explains these unconventional behaviours are not a common sight but when they observe these behaviours in the area the take it as an indicator of disasters. Generally, the domesticated animals like pigs, cows, hen, etc., gives them the indicator through wailing or howling at night or croaking sounds of frog differently at day time who understand the nature and helps to predict such disasters. There are numerous case studies wherein animals have predicted the onset of such disasters.

4.3 Folklore/Folktale (About Behaviours of Ants)

Before the floods Mising have also observed that ants (red ants) start moving to higher ground (like trees, roofs) and they start to carry their eggs, food which is indication that flood is expected very soon.

Demystifying the folklore/folktales

As ants have strong smelling capacity which is why they can't endure the water level rising then often the ants migrate from their original habitation to higher ground. Mising who have mastered these practices by seeing/observing the behaviour they prepare themselves to cope from upcoming floods.

4.4 Folklore/Folktale (Observing Behaviour of Zia (Dragonfly), Termites and Ants)

Traditional weather wisdom of Mising community by observing behaviours of the animals and insects, etc., like '*Zia*' (dragonflies), ants, termites, etc., which has been popular folklore till date and village elders who preserve these traditional practices and pass these to one generation to another.

Folklore/Folktales

The islander mentioned that with the start of monsoon from Asaad (mid-June) the community starts observing the behaviour of certain animals like Zia to predict rainfall. They mentioned that when they see a lot of Zia in the area or when dragonflies start flying in large groups in a particular area and mostly above the ground by 3–4 m which indicates flood like situation.

Demystifying the folklore/folktales

As female Zia's (Dragonflies) lays eggs either on water or in some cases within or inside the aquatic plant stems. It takes almost takes from one to three weeks for eggs to hatch and depends on climatic condition so when the islanders find large number of dragonflies the community predicts floods.

4.5 Folklore/Folktale (About Behaviours of Birds like White Breasted Water Hen)

As the Mising communities have been living in consonance with floods they have mastered over the animal behaviours in order to predicts floods in particular. As per the elders from Bebejiya Gaon.

> Our fathers and their father and we also predict flood by observing the changed behaviour of certain birds and animals which are seen in the villages when we hear the crows calling especially during late evening and night or White breasted Water-hen (locally known as Dahuk in Assamese) they started retracting towards the embankment which acts an mound or any high-rise area and we have seen or heard the bird cry especially before the onset of monsoon especially I have seen it during 1998 – 2000 flood which affected a lot of people.[32]

The community used these practices to prepare themselves from floods.

Demystifying the folklore/folktales

These birds' lives near the water bodies, open marshes, wetland or riverbanks or bodies. Hence, when the birds start retracting to other areas than their usual habitat like dry areas that's when the community predicts floods (Table 3).

5 Conclusion and Way Forward

In recent time, we have observed that the signpost of the development like embankment, dykes breach has taken more life in Assam which has led to making the Mising and other communities from Assam become a climate refugee, forcing them to be displaced from one place to another in different parts of Assam. Hence, it becomes an urgent reckoning that both IK and scientific knowledge should go hand in hand in DRR and the key is participation and integration of Indigenous communities in these initiatives to achieving the developmental goals and Sendai Framework of Action 2015–2030 to reduce the existing and new disasters. Analytically, it is vital that aboriginal wisdom knowledge should be recognized and acknowledged as an effective or valid method of knowledge for making evaluation at a higher level of governance, at the same time, being immune from getting exploited or getting misrepresented by using suitable methods or agencies in order to defend sensitive data or information at the same time (Taylor 2008). Legitimizing aboriginal wisdoms or knowledge base can possibly aid to mitigate the contemporary from the quick shift towards a Eurocentric or Western regime of few native or aboriginal communities, for the probable detriment of management and protection initiatives of the community. The island believes that living with flood is their fate and they have remained like this for generations. Most of the communities were entirely dependent on the Indigenous practices to prepare for flood. However, with time and intervention by Government Organization through early warning by ham radios and NGOs intervention like providing livelihood opportunities, raised hand pumps and toilets, savings generation programme through SHGs, awareness programme has aided to reduce the impact of flood on the island too.

The marginalization of IK by using a more mechanized, scientific approach or what is believed to be higher or a superior wisdom and knowledge base, that over the years has become the premise for majority of established strategies, initiatives

[32] Excerpts from the interview conducted in Bebejiya Gaon in 2015.

Table 3 Local knowledge (IK) and practices and its advantage and limitations

Indigenous knowledge	Measures/practices	Annotations or interpretations
Early warning/anticipation	• Observing behaviours of reptile, insects and animal • The direction of winds and measuring temperature and celestial spheres or objects • The colour of the Cloud or if they observe any unfamiliar sounds, variation in the flow of water or its colour, etc	• These information, wisdoms or knowledge base are only limited to only few community members, elders, priest, etc • Transmission of this information to everyone from is vital to preserves and keep these practices alive
Preparedness and coping	• Storage of food • Plantation of rice in deep water • Storing fodder at higher elevation • Constructing Stilt house (Kare Okum/Chang Ghar) or elevated stand either with bamboo and wood • Crafting country made boats or rafts either from bamboo or banana stem • Building stilt houses • Practice and usage of ethno-medicinal plants which are used during floods to cure small ailments	• Storage of food depends on availability of the food; also, economic status is an important factor for storage of foods and amount might not be enough • Deep rice water plantation might not be idle for the other places • The knowledge about of the use of ethno-medicinal plants is limited few community elders only
Assistance and recovery	• Reliant on the social networks of friends, family and close-knit relatives, etc • Consuming locally accessible resources and capital of the community and locally obtainable supplies or constituents to build makeshift shelters or sheds for cattle • Repairs and maintenance of house, road, embankment, etc., post-flood • Rescuing and safeguarding the livestock and provide veterinary care to them • Spiritual ceremonies, functions and rituals, etc., which aid to overcome from post-traumatic stress disorder	• Snowballing ambiguity or uncertainty, or poor socio-economic condition, implication of poverty and deficiency might lead to break down of their social bond or network, etc. That leads into community and people becoming more self-absorbed about their family's survival rather than thinking as collective • There are possibility of lack of local expertise and material in all post-flood situation and geographies as well

or programmes on DRR (Mercer et al. 2008). Hence, in order to increase resilience and coping mechanism of the Indigenous communities, it is important to develop a more democratize and participatory approach wherein the Indigenous communities can actively engage (Mercer et al. 2010). And their knowledge and wisdoms are integrated which is key in addressing the unseen prejudices which impede meaningful integration of IK in DRR which was also echoed by other scholars too that (Hiwasaki et al. 2014) at the grass-root-level DRR planners and implementers should allow the different constituencies to participated in different stages of disaster risk reduction to reduced their vulnerability. That's why it requires urgent reckoning and emerging prerequisite to acknowledge the native or aboriginal wisdom, knowledge and practices, etc., as an effective method of material and in order to make decision at policy level and legitimizing these practices could help to mitigate from disasters. In order to do so, the traditional ecological knowledge should be inter linked with the native social customs, traditions, folklore or its cultural values. Hence, the passage or percolation of this type of wisdom or knowledge base to each member of the community primarily among the younger generation by the elders, community leader or by community service organization through different means is significant to safeguard these knowledge base. That's why the contemporary disaster management plans designed for the communities requires assimilation of local or native knowledge which are made for the locale and these practices have progressed throughout long time period by instilling as per the prerequisites for local ecology and community living around here. Hence, it is vital that disaster management planners should recognize the position of native expertise, knowledge base and their practices in order to improved disasters plans or lessening the impact of upcoming disasters. It is that the elderly from the community engaged in transmission of folk tales or practices to share the local or native information or knowledge base with community, primarily with young adults by becoming comprehensive and inclusive in its approach for communication and adoption new forms of knowledge transmission that can be nontraditional like the usage of newspaper, loudspeaker, radio, social media, Whatsapp the Internet, etc. Being an approach for keeping the younger generations being absorbed, engrossed and stimulated; in order for being convinced that younger generation will do the knowledge disseminate or propagation of knowledge as extensively as likely. It is vital that these fora generate platforms for transmission, passage or exchange of information and knowledge base as well. Also, the DRR programmes should also include different intersectionality's like caste, class, gender, social status community relationship, etc. Like by Lennie (1999) identifying gender as important component in participation in DRR, he argued that DRR programmes need to be considered to the availability and daily schedules of women in order to ensure that they also participate in these programmes rather than only limiting them to 'spectator' during DRR and ensuring the decision-making is more democratic rather than person with power taking the decision on everyone's behalf.

- It is imperative to recognize that deluge is not only confined to the discourse of disaster management per se but also correlated with the development programmes and issue of conservation or safeguarding larger development gains by building development programmes more and more sustainable at the same time.

- This needs to be deeply examined of as the floods and erosion not only has economic, social impacts on the community but also is creating livelihood crises in the community.
- The use of this wisdom or IK during the times of floods and climate change requires an urgent reckoning.
- There is need of integrating these IKs with the modern-day disaster risk reduction plans by involving the locals in dissemination.
- Documentation of such IK and practices.

In flooded geographies like Majuli wherein the community has limited knowledge or information about the modern-day disaster management technology, Indigenous methods of weather forecasting based on observing their natural environment play a key to their coping mechanism. Thus, it is vital to have a more holistic approach in disaster planning by integrating these practices. The disaster management or risk reduction plans designed for commune requires assimilation of local and native practices, knowledge base which are made for the locale and over the longest time period by inculcating the prerequisites of the local ecology and community.

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Assessing Public Perception on Developing Colombo Municipal Council Area as a Green City

Rasmiya Niyas and Fareena Ruzaik

Abstract The Colombo Municipal Council area shows a significant trend on increasing urbanization rate and development every year. However, the current high urbanization rate of Colombo municipal council area and its impacts, reduce the green spaces gradually and remarkably. As a result, various social, health, and ecological problems have arisen. In order to escape from these problems, it is recommended to transform the Colombo municipal council area into a green city. So, this study explores the public perception on designing green city in Colombo municipal council area and investigate the problems and challenges faced by the public due to the current city structure. A questionnaire survey was conducted to obtain perceptions from 140 respondents randomly chosen from residents living in the study area. Further secondary data were also used in this study. 93.3% of respondents of the questionnaire have at least medium knowledge of green cities and 92% of respondents have at least medium knowledge of sustainable development. The results indicate, due to the current city structure of Colombo municipal council area 76.9% people feel respiratory problems and 78.6% feel excessive heat and consequent massive attitudinal and behavioral changes. 92.9% people also experience depression and irritability. As a result, 100% of the people have expressed their desire to transform the Colombo municipal council area into a green city. In other hand, only 79% of them think that transforming the Colombo municipal council area into the green city is a possible sight. In contrast, 21% of those surveyed said it would be impossible to turn the Colombo municipal council area into a green city. The reasons stated for this are political interference, overcrowding in small areas, improper constructions, and ambiguity for most of the general public. However, it has become imperative to build the Colombo municipal council area as a green city by overcoming above obstacles. Therefore, based on this study, utilization of public transport, use of eco-friendly vehicles, planting suitable trees on both sides of roads, paths and highways, planting of eco-friendly plants in terraced floors, introducing green city building methods during building construction, carrying out proper waste disposal projects were identified as some possible ways to design the Colombo Municipal Council area as a green city.

R. Niyas · F. Ruzaik (✉)
Department of Geography, University of Colombo, Colombo-03, Sri Lanka
e-mail: fareena@geo.cmb.ac.lk

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1 Introduction

Cities are growing rapidly in the twenty-first century. By 2020, 56.2% of the world's population live in cities. The global urbanization rate in 2020 is 2.9. According to Asia, "Asia is urbanizing at a rapid rate. While in 1950 the region was predominantly rural, with only 17% of its 1.4 billion people living in cities or towns, recent United Nations projections (2004) indicate that by mid-2022, 55% of Asians 2.7 billion people will live in urban areas." (Green Cities—Think Asia 2012). Especially Kuwait and Singapore are the largest urban population countries in Asia. Yet in most other Asian countries urbanization continues to increase today. Based on that accordingly, 18.59% of the total population of Sri Lanka lives in cities. The total city population of Colombo in 2020 is 4 052 088. Of these, 647 100 live in the study area of the Colombo Municipal Council area. The urban development of the Colombo Municipal Council area is increasing every year. But unfortunately, this urban development has disrupted the balance of the natural environment and reduced the greenery in the city of Colombo. "The green space change has been remarkable since 2001, with annual reduction rates of 0.46 km^2 (1980–1988), 0.39 km^2 (1988–1997), 0.37 km^2 (1997–2001), 1.37 km^2 (2001–2011) and 0.71 km^2 (2011–2015)" (Li-Pussella 2017).

Due to this greenery reduction and the current city structure of Colombo Municipal Council area public face various problems and challenges. Such as respiratory problems, stress and irritability, high heat, rapid spread of infectious diseases, restlessness, air pollution, unhealthy behaviors, and changes in social behavior. This situation is causing serious shortcomings in the development of the Colombo Municipal Council area. So, to avoid such problems, the Colombo municipal council area should be transformed into a green city.

According to UNEP the greening of cities requires some, or preferably all, of the following: (1) controlling diseases and their health burden. (2) Reducing chemical and physical hazards. (3) Developing high quality urban environments for all. (4) Minimizing transfers of environmental costs to areas outside the city. (5) Ensuring progress toward sustainable consumption" (UNEP 2011). And according to Khan the Green cities have clean air and water and pleasant streets and parks. Green cities are resilient in the face of natural disasters, and the risk of major infectious disease outbreaks in such cities is low. Green cities also encourage green behavior, such as the use of public transit, and their ecological impact is relatively small" (Khan 2006). Based on these, the Colombo Municipal Council area can be transformed into a green city by making such changes. Through this people living in the Colombo municipal council area and the entire country will enjoy various social, economic, and ecological benefits by transforming Colombo municipal council area into a green city.

So, by rebuilding Colombo Municipal council area on the basis of the green city concept we can avoid the problems that people face in the present and the problems that future generations will face. Specially we can leave a clean and sustainable environment to future generations. Therefore, based on that, this study investigates the ecological, social, and health problems faced by the public due to the current city structure of Colombo Municipal Council area. Similarly it identifies the potential of designing Colombo M.C. area as a green city and it assesses the awareness level of public about the green city concept.

1.1 Literature Review

In order to carry out this research, Literature review was carried out from related books, research articles, international journals, reports, and various documents related to the research topic.

Institute for Advanced Sustainability Studies (IASS) (2016) clearly analyses the Green city concept by the IASS work paper on how green is a "Green City"? A review of existing indicators and approaches is very comprehensively with a several definitions. Khan (2006) defined that "Green Cities have clean air, water, pleasant streets and parks. green cities are resilient in the face of natural disasters and the risk of major infectious disease outbreaks in such cities is low. green cities also encourage green behaviour, such as the use of public transit, and their ecological impact is relatively small."

The research of Wickramasinghe et al. (2016) on Spatial and Temporal Changes of the Green Cover of Colombo City in Srilanka from 1956 to 2010, clearly analyses the decrease of green cover in Colombo City using aerial photographs and IKONOS maps. According to this research, the green cover of Colombo City declined from 35.67 to 22.23% from 1956 to 2010. In 2010 only four wards of Colombo had green cover over 30% of the total land. Similarly Li and Pussella (2017) compares Colombo city with other major cities in the South Asian region by his research on "Is Colombo city, Srilanka secured for urban green space standards?". The results show the decrease of green space in colombo city and the per capita value recorded in 2015 is below WHO standard of $8m^2$. And also it defines the green space change has been remarkable since 2001, with annual reduction rates of 0.46 km^2 (1980–1988), 0.39 km^2 (1988–1997), 0.37 km^2 (1997–2001), 1.37 km^2 (2001–2011), and 0.71 km^2 (2011–2015).

European Nursery stock Association explained the Positive effect of European Green Cities, the "Parks with trees, shrubs, water basins and recreational areas as well as more extended forest lands surrounding urban centers will mitigate the consequences of climate change in urban areas, heath, weather, biodiversity, health and will also play a positive role in social cohesion." Moreover, significance of constructing green buildings are described and briefly explained by the (World Green Buildings Council 2016–2020) on The benefits of green buildings. According to that, green cities provide a number of positive effects to environment, economic, and society. They help to achieve sustainable development goals and economic growth, reducing climate change, and creating sustainable communities. When referring to the economic benefits of green buildings, world green buildings council mentioned that, "Canada's green building industry generated $23.45 billion in GDP and represented nearly 300,000 full-time jobs in 2014" (Canada green buildings council/The Delphi Group 2016).

1.2 Objectives

1.2.1 Main Objective

Assessing Public Perception on Developing Colombo Municipal Council area as a green city.

1.2.2 Specific Objectives

1. Investigating the problems and challenges faced by the public due to the Current City Structure of Colombo Municipal council area.
2. To evaluate the awareness level of public about the green city concept.
3. Identifying the potential & the possible ways of designing Colombo Municipal Council area as a Green city through the public perception.
4. To assess the contributions that people can make on designing Colombo municipal council area as a green city.
5. To recommend and promote the green construction in Colombo Municipal Council area.

Research Questions

1. What are the problems and challenges faced by the public due to the current city structure of Colombo Municipal council area?
2. How is the awareness level of public about the green city concept?
3. How the public think about the possibility and the possible ways to convert Colombo municipal council area as a green city?
4. What kind of contributions people can make on designing Colombo municipal council area as a green city?
5. What are the suggestions and recommendations that can be to convert Colombo Municipal Council area as a green city?

2 Research Methodology

2.1 Study Area

The Spatial Location of the Study area is Colombo Municipal Council area. It is located in the Colombo district of the western province of Sri Lanka. There are 35 Grama Niladhari divisions in the Colombo M.C. area. According to the 2011–2012 Census, the population of the Colombo Municipal council area was 555,031. 318,048 lived in the Colombo Divisional Secretariat Division (the Northern part of the city) and 236,983 lived in the Thimbirigasyaya DSD (the Southern part). It is one of the largest employers in the country with over 12,000 employees (Wikipedia, n.d.). Especially Colombo Municipal Council area is one of the highly urbanized areas in Sri Lanka. Therefore, the study area is highly suitable for the research (Fig. 1).

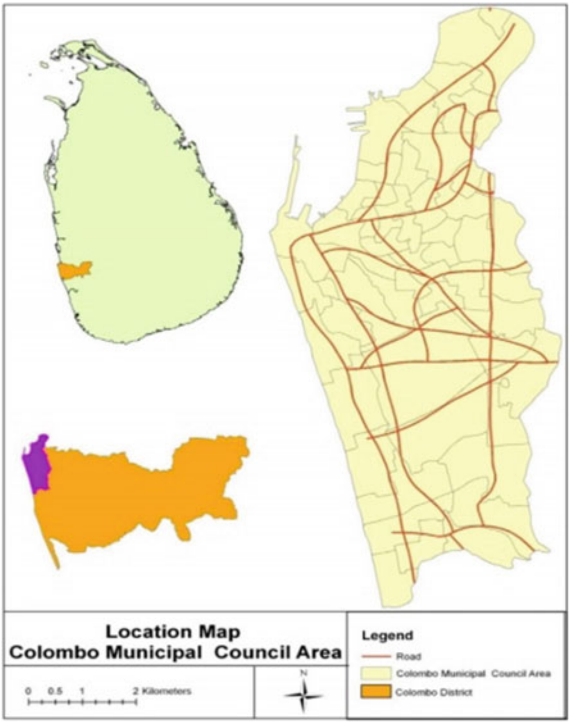

Fig. 1 Location map of Colombo municipal council area. *Source* Sustainable Housing and Urban Development (2019)

2.2 Data Collection and Analysis Methods

This research is based on primary and secondary data. Primary data collection method has been obtained through questionnaire survey in the study area. 150 questionnaires were provided to the public who lives in Colombo M.C. area to assess the Public Perception on designing Colombo M.C. area as a green city. The questionnaire had following parts with closed and open ended questions.

(a) Part I–General information of respondents.
(b) Part II–Understanding of green city concept.
(c) Part III–Urban structure of Colombo municipal council area.
(d) Part IV–Designing Colombo municipal council area as a green city.

Due to the covid 19 global pandemic situation some questionnaires were provided via Google form. The Purposive Sampling method has been used in the questionnaire survey of primary data collection. The 140 participants have responded to the survey. Following table shows the participants of the questionnaire survey (Table 1).

According to the survey, the majority of the respondents were graduate females (n = 38,56%). These female graduates were aged between 20 and 50 years old. The whole non-professional respondents were female (n = 20), aged between 25 and 50. The largest number of male respondents were Professionals (n = 18, 80%) and Merchants (n = 16,100%). The professionals were aged between 30 and 50 years, and the majority of the merchants were aged between 25 and 45. The majority of the graduates live more than 3 years in the study area (n = 54, 79.4%). More than half of the professionals and merchants live more than 5 years in the study area. The whole number of non-professional respondents lives between 6 to 10 years in the study area. So finally, most of the respondents live between 3 and 10 years in the study area. Moreover, the secondary data have been obtained through Books, Researches, Research Articles, e-magazines, and Internet Sources. The Microsoft Excel method was used to analyze the collected primary and secondary data.

Table 1 Category of the respondents of the study

Category of respondents	Number of respondents	Percentage of respondents %
Drivers	14	10
Graduates	68	49
Professionals	22	16
Merchants	16	11
Non-professionals	20	14

Source Field survey 2020

3 Results and Discussions

3.1 Level of Awareness of People About the Green City Concept

The awareness of the people about the green city concept was measured by using the created rankings on Likert scale. In this scale the following 1–4 points of awareness scales were used, 1 < Very low, 2 < Low, 3 < Medium, 4 < High level. The mean scores were calculated for all respondents groups to evaluate the awareness of each group respondents on green city concept and sustainable development. This type of analysis was based on a similar study that was done by (Sichani and Banda 2017).

According to the survey, this study finds that professionals have the highest level of awareness among the respondents at the level of 3.6. Most of them are Lecturers and Teachers. The non-professionals have the lowest awareness at the level of 1.1. Most of them are house wives and ladies. Drivers and the merchants have the low level of awareness at the level of 2.2 & 2.1. The graduate respondents have medium level of awareness at the level of 3.1. Most of the graduates are government university undergraduates. So finally, most of the respondents of the questionnaire do not have the high level of awareness of green city concept. But most of the respondents have medium level of awareness of green city concept. The following figure shows the level of awareness of categorized respondents (Fig. 2).

The 93.3% respondents have heard about green city concept through media, social media, workshops, higher educational syllabuses, researches, and books. But unfortunately 6.7% of the respondents haven't heard yet about the green city concept. 80% respondents have seen the green city through several sources. 92% of them have felt natural beauty and peace of mind when seeing the greenery city. 86.7% of them have realized the differences between none greenery urban cities and green cities. And 20% respondents haven't seen the green city yet in any sources. Further 92.9% of the total respondents agreed that the green cities will help for the sustainable development.

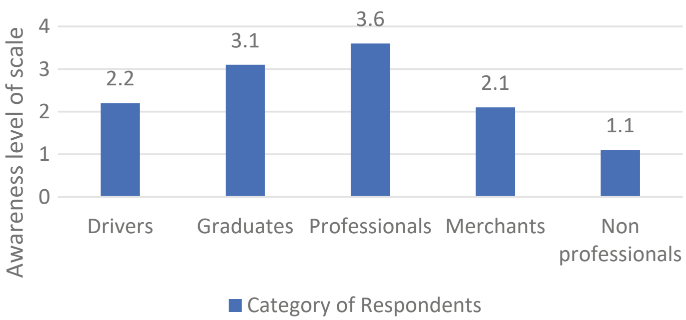

Fig. 2 Awareness level of respondents. *Source* Field survey 2020

3.2 Problems & Challenges Faced by Public Living in Colombo Municipal Council Area

The perceptions of the public about the current city structure of Colombo municipal council area were scaled with a ranged scale from strongly agree to strongly disagree. According to that 73.3% respondents disagreed with the current constructions of Srilankan cities are sustainable. 75.7% participants agreed with the current city structure of Colombo municipal council area isn't environmentally friendly and 64.7% of them feel that the current environment of Colombo municipal council area is polluted. They strongly agreed that the excessive use of fuel vehicles and emission was the main reason for it.

Therefore, the public face various problems and inconveniences due to the current city structure of Colombo municipal council area which has lost lots of greenery today. Based on the data obtained from the samples selected for the study, the following issues were mainly identified. (1) Respiratory problems; (2) depression and irritability; (3) congestion; (4) high heat; (4) rapid spread of infectious diseases; (5) excessive vulnerability to natural disasters; (6) air pollution; (7) water pollution; (8) waste disposal problems; (9) high traffic, and (10) poverty.

Accordingly, 76.9% of the samples selected for the study suffer from respiratory problems in the Colombo Municipal Council area. This is because people do not get the opportunity to breathe clean air when entering the Colombo M.C. area. Especially public who newly enter to the Colombo area from rural areas face this issue mostly. Although this study indicates that 92.9% of the general public in this area feel disturbed and irritated due to the noise of vehicles and congested factories. In addition 78.6% people feel hot when entering the Colombo M.C. area than in other cities. Moreover this study found that congestion and traffic jams cause many changes in people's attitudes and behaviors due to prolonged roadblocks and waiting on the streets (Fig. 3).

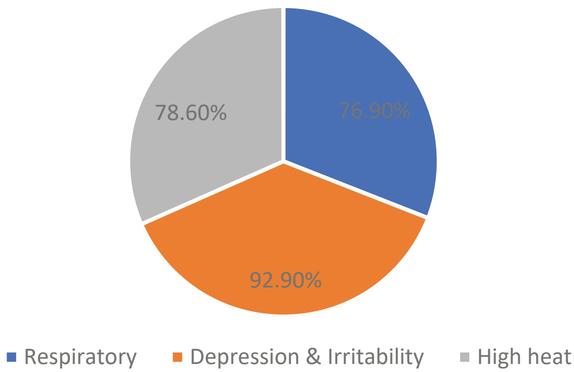

Fig. 3 Main problems faced by the public due to the current city structure of colombo municipal council area. *Source* Field survey 2020

3.3 Public Perception About the Potential & The Possible Ways of Designing Colombo Municipal Council Area as a Green City

According to the data obtained through the survey data collection system, 100% of the people have expressed their desire to turn the Colombo Municipal Council area into a green city. But only 79% of them think it is possible to make the Colombo Municipal Council area as a green city. 21% of those surveyed said it would be impossible to turn the Colombo Municipal Council area into a green city. The main reasons stated for this are political interference, overcrowding in small areas, improper construction, excessive usage of non-sustainable fuel, ambiguity for most of the general public, improper development projects, and non-sustainable city structures. Especially 57.1% of participants strongly agreed that the designing Colombo municipal council area is a mandatory requirement.

However, it has become imperative to build the Colombo Municipal Council area as a green city by overcoming those obstacles. Based on that this current study has identified the following ways as possible to design the Colombo municipal council area as a green city through the public perception. **(1) Utilization of public transport**—The increase in the number of self-driving vehicles in the Colombo Municipal Council area has led to vehicle emissions and congestion. So, while reducing the use of self-driving vehicles and improving public transport, vehicle emissions and air pollution will decrease automatically. Thus, it will prevent respiratory problems and health problems and reduce traffic noise, congestion, noise pollution, and psychological problems such as stress, irritability, and mood swings of the public; **(2) increasing the usage of eco-friendly vehicles** such as bicycles, rowboats, velomobiles, horses and carriage, solar vehicles, and green cars; **(3) planting of eco-friendly plants in terraced floors in the Colombo Municipal Council area**. According to NASA's identifications the following plants are the most effective air purifying plants. So, it would be better to introduce these plants in the Colombo Municipal council area and plant them when constructing buildings, streets, highways, etc. Garden Mum, Spider Plant, Peace Lily, Dracaena, Dwarf Date Palm, Boston Fern, Kimberley Queen Fern, Chinese Evergreen, Bamboo Palm, English Ivy, Variegated Snake Plant, Red-Edged Dracaena, Florist's Chrysanthemum, etc. (EPSTEIN, CORY 2016); **(4) introducing green city building methods during the building constructions; (5) making political policies and laws related to green urbanization; (6) planting suitable trees on both sides of roads, paths, and highways; (7) carrying out proper waste disposal projects; (8) the government should focus more on sustainable development rather than rapid development; (9) giving the complete awareness to the people in all three languages; and (10) Making green houses, corridors, and walls in Colombo municipal council area**. Especially these activities can be done successfully by setting up a team to transform the Colombo municipal council area into a green city and thereby carrying out a number of programs. So, by making the above changes in the Colombo Municipal Council area, it can be transformed into a green city and achieve various ecological, sociological, and economic benefits.

When the participants surveyed about the benefits of designing Colombo municipal council area as a green city 97% strongly agreed that the designing Colombo municipal council area as a green city will make a massive contribution to the development of the country. And it will bring about many positive changes in the economic sector of the country. Thus, the country's tourism sector's growth will be multiple. All of the graduates agreed with the statement that states, the designing Colombo municipal council area will bring more changes in the individual, social life, and behavior of the public. According to secondary data analysis about the benefits of green cities (Magnaye and Dina 2018) cited that "there is a strong relationship between green open space, people's mental and physical well-being and presence of biodiversity and wildlife habitats within established built environments." European Nursery stock Association explained that the "Parks with trees, shrubs, water basins and recreational areas as well as more extended forest lands surrounding urban centers will mitigate the consequences of climate change in urban areas, heath, weather, biodiversity, health and will also play a positive role in social cohesion." And also, they describe that "the green environment improves the quality of life. Patients recover much faster in a green environment, residents of green neighborhoods make less use of healthcare facilities, and employees of companies surrounded by green feel much happier. In addition, a city park will encourage people to exercise and relax there, which will improve their health. Especially children will grow up more harmoniously and perform better in school if they live closer to nature" (ENA European Nurserystock Association 2018).

3.4 The Contributions That People Can Make on Designing Colombo Municipal Council Area as a Green City

Moreover when respondents surveyed about the contributions of public that they can make on designing Colombo municipal council area as a green city they were asked "are you ready to embrace the below changes that this project can bring in your life." The following findings were defined (Table 2).

According to data analysis 61.4% of participants were ready to use public transport if they were designed as healthy public transport. But 38.6% of them are not ready to use public transports even if they were healthy. The reason identified for that is it may betake long time, heavy traffics, not freedom, etc. Most of the respondents were also ready to use eco-friendly equipments if they were introduced nationally.

Specially all of the participants were ready to plant eco-friendly trees in houses, schools, offices, working places, public buildings, streets, etc. But they requested the government to introduce and provide eco-friendly trees and planting systems. Moreover 68.6% of respondents are ready to adhere to green city building systems when constructing houses and buildings. And 82.8% agreed to Adherence to the government policies related to green city project. Most of them are graduates and professionals. So finally most of the participants ready to embrace the changes that

Table 2 Responses of participants about the contributions on designing Colombo municipal council area as a green city

	No. of responses of participants	
Changes	Yes	No
Using public transport	43	27
Use of eco-friendly equipments such as green car, bicycle, etc	62	08
Planting eco-friendly trees	70	–
Adherence to green city building systems when constructing houses and buildings	48	22
Adherence to government policies related to green city project	58	12

Source Field survey 2020

the designing Colombo municipal council area as a green city will bring in individual and social life.

4 Conclusion and Recommendations

Due to the current city structure of Colombo municipal council area, the public is facing various health problems. It also leads to various ecological problems and pollution. These issues will pose a major challenge to Sri Lanka's journey toward development and the sustainability of future generations. In this context, the current city structure of the Colombo Municipal Council area is not satisfactorily developed. It is also doubtful whether it will achieve the goals of sustainable development. Therefore, it is imperative to transform the Colombo Municipal Council area into a green city in order to achieve the goals of sustainable development. Although it is difficult to transform the Colombo Municipal Council area into a fully green city, but it is possible to gradually build a partially green city.

Political policy classifications and the participation of the public are crucial in this project. The government, in collaboration with other private companies, can raise awareness about the green project to the people in all three languages and carry out activities such as honoring, encouraging, and rewarding the companies, architects, and individuals who implement the green city project. In particular, it is imperative that the government actively implement proper waste disposal schemes, ban vehicles that pollute the environment, improve public transport and implement tree planting projects covering the entire area of the Colombo Municipality (Ruzaik 2016).

Further the general public needs to be aware of the problems caused by the current urban structure and their consequences and act accordingly. It is essential for every individual to keep the environment around him in harmony with green and clean. For this, public can use healthy traditional methods and new techniques in home gardening and tree planting. It is also the chief duty of the public to give their full support and contribution to the projects and practices being undertaken by the Government and the private sector in relation to the Green City in the interest of future individual and social interests. Through this, individuals and communities can work together to transform the Colombo Municipal Council area into a green city and build a sustainable city.

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Climate Change and Its Impacts Assessment Through Geospatial Technology-A Theoretical Study from Extreme Weather Perspective for Disasters Resilient India

Niranjan Sahoo

Abstract To meet the bundle of human wants, anthropogenic activities with industrialism helping -in an abruptly spike in global temperature has witnessed on global scale. Some climate drive phenomena pave ways for the melting of polar ice caps, rise in temperature helps intensify storms, torrential downpour and flood, coastal inundation owing to rise in sea level subsequently. Utility and Application of Remote Sensing and GIS in climatic impact analysis at regional level is very much required. Geoinformatic techniques in impact analysis are very much essential for effective disaster management by using satellites. Sea level rise study techniques and challenges are stemming from the use of LiDAR, DEMs Based on LiDAR, etc., approaches to correcting discrepancies between vertical referring system or land and tidal datum transformation. LiDAR DEMs integrated into a GIS can be used to identify that are vulnerable to Global Sea Level Rise. This paper is an attribute of case study, and personal observation on climatic events. The objectives of the chapter are to draw an apparent illustration on climate change and resulting disasters. It focuses on regional analysis in order to find out the consequences of climate change through Geospatial technology for disaster resilient society. Secondary data from, UN climate change department, World Meteorological Department, National Institute of Disaster Management, newspaper articles, etc., were collected and analysed in a bid to reconnoitering impact of climate change at regional level by inspecting into the climate crisis. It's obvious that climate change has direct impact on emerging disasters. An efficient system for monitoring and impact assessment through geospatial technology needs to be developed.

Keywords Climate change · Geospatial technology · Disasters management · Mitigation · Resilient

N. Sahoo (✉)
Department Of Geography, Utkal University, Vani Vihar, Bhubaneswar 751004, Odisha, India
e-mail: niranjansahoo743@gmail.com

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1 Introduction

Amid population rise and to meet the needs of human beings, industrialism emerged as a new trend which subsequently forms the urbanism for economic development. And hence anthropogenic activities, and industrialism helped in an abrupt spike in global temperature. Thus, vulnerability and cumulative impacts at regional level have pushed its habitants and livelihood at stake. Extra weathering activities help in rising temperature and pave ways for the melting of ice caps, drought, rise in temperature which subsequently intensifies more powerful storms along with torrential downpour as a result of which, flooding, coastal inundation owing to rise in sea level adversely affects the inhabited area. Climate change-related disasters in tropical belts, torrid, temperate and frigid are taking place across the countries. Different landscapes such as mountains, coastal belt, plains and deserts shall be under tremendous threat from the climate change point of view in general and shall push its people, ecology and economy into vulnerability in particular. The physiographic divisions of India are comprised of the northern mountainous region, desert, coastal, etc. Coastal inundation, amid propound seasonal irregularity, the desert will have a deficit in water which will lead the plain's life and livelihood of the habitants under prone. Especially in the tropical belt the climate change has become more propound since industrialism. The chapter is a research based on some case studies, personal observation on climatic events and such vivid impacts falling on rest of seasons is very supportive evidences in the matter of disasters and climate change. Impact assessment is indeed an approach which enables us to tackle the unprecedented crisis through the application of technology in general and the application of Geographical Information System and Remote Sensing in particular. In order to study possible issue pertaining to climate-related disasters in India, empirical modelling was used which was necessary for estimating the rate of climate change and its resulted disasters by analysing and monitoring spatial–temporal characteristics of elements of weather at regional level those having geographical variability.

2 Climate Change and Disasters

Natural disasters are adverse events caused by the nature that exceed the tolerable limit and make human civilization very hardship. Ramifications in colossal loss of economy, destruction of settlement and environment and severity and magnitude of disasters continue to grow at a rapid pace under the ascendancy of global climate change (Sahoo and Satpathy 2020). Twenty-first century is well as the era of climate change, as, since 1990 the average global temperature growth was witnessed at a rate of 1.9 °C. In an age of climate change, we have witnessed a rise in the mean temperature on the global scale as a result of which, the landscape which is more susceptible to climate change suffers a lot. Polar ices cap melt and rising sea level, exposing the coastal belt inhabitants to greater vulnerability and unpredictability.

(Sahoo and Satpathy 2020). Hence, amidst rise in temperature on global scale extra weathering rise in temperature is paving ways for the melting of ice caps, drought, rise in temperature intensifying more powerful storms along with torrential downpour and flood, coastal inundation owing to rise in sea level subsequently bearing the coast in the forms of disaster. Climate change-related disasters especially in tropical belts have taken place across the nations. Changes in temperature properties and patterns in elements of weather give a sense of how climate is on full swing and its cumulative impacts are being reflected in the form of disasters. Some recent natural disasters such as cyclones Idai and Kenneth, Australian wildfires, East Africa drought, South Asia floods dry Corridor in Central America are the attribute in this regard and could be appropriate indicators of climate change.

Climate change is considered to be the single most dominant factor which reflects as a multi-faceted cause of disasters in the twenty-first century. Climate change owing to changes in temperature spike affects different landscapes such as mountains, coastal bastions, plains and deserts. Impact at the four aforesaid landscapes is affecting ecology, people and their economy to a greater range.

3 Climate Change and Impact at Regional Level

The regions' geographical variability in location, topography, nature of landscapes, etc., play a pivotal role in determining vulnerable to natural disasters caused by climatic changes which may have a big impact on economic and social infrastructure and affect the lives of the dwelling region. As the chapter primarily focuses on the climate change, author has broadly discussed on the impact of climate change and its impact on four major areas such as mountain, coastal, plain and desert areas.

In this section, the author reiterates spike in average global temperature helps in ice sheets melting, sea level rise and storm surge owing to sea surface temperature rise up. In mountainous landscape melting of valley glacial heavily affects its surrounding environment and its habitants at a greater range. Apparently, coastal disaster is a combined action of two phenomenons, sea level rise and an obvious coastal disaster from the storm surge which getting intensifies amid sea surface warm up. Both leave footprints of annihilation across the coastal bastion and coastal inundation which affects life and livelihoods of the dwellers in the coastal area.

In a bid to find out the impact of climate change, the author has focused on four major aforesaid landscapes, Mountainous region, Coastal region and Plain region. They have been analysed in detail as follows.

3.1 Mountainous Landscape

An average spike in global temperature profoundly may proliferate many issues. Outcomes of many research divulge that as much as one-fourth of the global mountain glacier could be vanished by the end of 2050. However up to 50% of mountain glaciers could be wiped out by the end of 2100 (Kuhn 1993; Oerlemans 1994; IPCC 1996). Between 1999 and 2001, numerous studies took place in a bid to draw a bead on the climate change and the rate at which the glacier melts. It's been observed that, in Valley of the Himalaya, the ice sheets have retreated by precisely 1 km since the regime of fourteenth century to mid-nineteenth century which is apparently known as Little Ice Age (Mool et al. 2001). An exploration entitled with 'The Chinese glacier Inventory' was followed by the Chinese Academy of Sciences. The Chinese Academy of Sciences had heralded some outcomes out of their research. As per their outcomes, during the last 24 years there has been a 5.5% contraction in the volume of China's 46,928 glaciers. This finding is equivalent to the ablation of more than 3000 sq km of ice. The study prophesies that if climate tends to change to this extent, then about three-quarters of China's Glaciers would be wiped out by the year 2050, and if the geomorphic process of ablation in the glacial preponderated mountains continues to this extent, then almost all would be wiped out by the year 2100.

Some of the glacial are retreating at a very fast pace in the Indian region of the Himalayas, this contemporary trends had admittedly started during the regime of Post glacial time. Siachen and Pindari Glaciers are notable of such retreating glacial. Siachen and Pindari Glaciers are retreating at a pace of 31.5 m and 2.33 m per year respectively (Vohra 1981). The Gangotri Glacier is retreating at an average pace of 18 m per year Thakur et al. (1991). The adherence of Shukla & Siddiqui (1999) on the Milam Glacier which is positioned at the Kumaon Himalaya evaluated that the ice retreated at an average rate of 9.1 m per annum between 1901 and 1997. Dobhal et al. (1999) supervised the ideal fluctuation of Dokrianic Bamak Glacier in the Garhwal Himalaya and they found 586 m of receded during the period 1962 to 1997.

There are many supportive evidences for assumptions that glacial melting at an unprecedented rate is an indication of climate change. Valley glacial retreats, and sheering of glacial cause avalanches in the inhabited region of the mountainous landscape. In mountainous valley region glacial retreats and causes vivid impact on both ecology and tourism-based economy of the region after natural beauty of the glacial region being degraded. For example Northern Mountain ranges of India are the abode of glacial. If valley glacial melts owing to the cumulative impact of climate change then it is for sure shall lose its relevance on being a hub of tourism, and having endowed with hotspot of tourists, which would be a major cause in lacking tourism attraction and must have a major impact on the local economy in near future. Thus, from ecological perspective, many flora and fauna indigenously found in these regions would be wiped out amid the prevailing inhospitable climate and hence apart from environmental disasters impact of climate change will result in the downfall of local economy.

3.2 Coastal Landscape

Coastal regions are usually densely populated and hob of tourism, economic activities, etc., and hence rise in sea level not only makes depopulation by making climate refugees but also people's livelihood will be wiped out, so global sea level rise has been in limelight in the aspects of disaster.

researches. In the climate change regime, coastal erosion takes place due to heavy tidal surge under the impact of numerous agents like high tide with huge volume of sea water in the monsoonal spell, gravity motion, human interfaces on the coast, modification of coastal landform for the seek of human use are treated as grave cause in light of rapid coastal erosion. (Sahoo & Chatterjee 2018).

Since forth 1880, it's been noticed that the mean sea level was about 8 to 9 inches on global scale, with about a third of that coming in just the last two and a demi-decade. The rise in water level is mostly owing to an amalgamation of melted water from glaciers and ice sheets and thermal aggrandizement of seawater, as it warms up in an era of climate change. During 2019, global mean sea level stood at 3.4 inches which was above the year of 1993 average, the highest annual average in the satellite record (1993-present). From 2018 to 2019, global sea level rose 0.24 inches, looking at the aforesaid data we can restate that global sea level rise is a universal matter of grave concern. From 2018 to 2019, global sea level rose 0.24 inches. Amidst rise in temperature and warm up the sea surface temperature augmentation of more powerful storm put its habitants and settlement at stake as coastal region having been influenced by maritime climate and vulnerable to three types of disasters namely cyclone, tsunami and storm surge. Global temperature and global mean sea level are on high parallel and continue to rise till now. This is resulting in a range of impacts including increased flood risk and submergence. Salinization over the standing crops leads to loss in agriculture. Surface and ground waters, the potential human and ecosystem impacts in the twenty-first century are significant but uncertain. Veritable impacts will depend on a range of changing factors in addition to the level of sea level rise and climate change, including numerous factors which are human-controlled such as coastal land use and management approaches. Sea level rise will only directly impact the coastal zone, such changes raise significant concern due to the high agglomeration of natural and socio-economic values located there. Coastal belts are a hub for tourism, trade and other lucrative economic activities. Thus, there is a vying between human beings in a bid to explore coastal region in an era of climate change such coastal bastion's life, livelihood vigorously get paralyzed after being heated by oftentimes disasters. Such sea-based natural hazards turn down into catastrophic disasters as a consequence of both economy and ecology of the region hampered to a greater extent. This is expected to increase by 50% by the end of 2030, and these people may face the threat of extinction. To add to this, each year 10 million people experience coastal floods due to storm surges and land fall of cyclones, and 50 million will be at risk by 2080 (Nicholls 2004).

Urbanization is an important trend and large coastal cities having more than 10 million people are projected to be affected with many smaller cities and towns clustered close to the coastline shall be under threat (Nicholls 1995; Small and Nicholls 2003). The coastal zone is a major focus of human habitation and economic activity, as well as being important ecologically (Holligan and deBoois 1993; Turner et al. 1996; Sachs et al. 2001).

Nine states and four Union Territories come under the coastal region of India. The east coast lies in between the Eastern Ghat ecosystem and the west coast lies in between the western Ghat ecosystem. The west coastal strip elongates from the Gulf of Cambay in the north.

to Cape Comorin (Kanyakumari). Five hundred and sixty million people live in this coastal region. One hundred and seventy-one million people in these coastal states are directly affected by floods and cyclones followed by torrential rain. In addition, approximately 4 million people comprising 8, 64,550 fishermen households are affected by these disasters. Further, climate change related to sea level rise increases the vulnerability of the coastal ecosystem and economy by posing a threat to many coastal cities, urban centers and coastal populations in the developing countries that have very poor adoptability capacity.

Satabhaya village is positioned on the coastal district of Kendrapara in Odisha is being scathingly attacked by climate change phenomena and has been prone to natural calamities like the deposition of sand dunes causing great havoc to the inhabitants since the vivid impact of climate change is in reinforced coastal inundation due to storm surge and tidal inundation into the coastal plains makes agriculture especially rice belt of eastern Odisha makes infertile In Odisha, coastal plains especially eastern coastal district of Odisha where inundation of areas with salt water, thereby making the land mass infertile for generations (Sahoo and Satpathy 2020).

3.3 Plain Landscape

The plain region being fertile in nature and is best suited for the practice of agriculture, which provides a hospitable climate for human habitation. In India over 70% of rural households depend on agriculture as their principal means of livelihood. Agriculture, along with fisheries and forestry, accounts for one-third of the nation's GDP and is its single largest contributor. As per the census of 2011, 263 million people are engaged in the agriculture sector and over half of them are agricultural labourers. In the era of climate change and irregularities in seasonal cycle in general and erratic nature of monsoon in particular will have a vivid impact on people and economy. The nature of the rainfall over the monsoon months has also been erratic. For example, in 2020, Delhi experienced excess rains in July, followed by 72% less than average rainfall in the first half of August. But the agricultural productions get a setback as crops are unable to cope with the erratic nature of climate and hence low production is an obvious phenomenon. In the aftermath of a disaster its subsequent impact takes place and affects agriculture, the livelihoods of these people are affected, pushing them into the trap of poverty. In case of Indian context, plain landscape is a physiographic division out of rest, on which agriculture-based human settlement, is predominantly found and colossal loss of life of people, animal and economy are substantially affected.

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3.4 Desert Landscape

Although, a desert is sparsely inhabitable than those of the rest of landscape, in hospitable environment, scanty rainfall and sand topography impede agriculture practice and are faire attributes for less human habitation. Ongoing acute climate crisis in the desert landscape will make further inhospitable climate, harsh of the dwellers of the deserts. Global warming would have much impact on the world's hot deserts but even small changes in temperature or precipitation tendency could drastically impact flora and fauna in the desert. Global warming is accelerating the prevalence of drought, which dries up underground water table. Temperature or precipitation tendency could drastically impact flora and fauna in the desert. Global Warming is accelerating the prevalence of drought, which dries up underground water table. Deserts are mainly found in the western part of the continents and have direct impact on trade wind on the climate of deserts so in the era of climate change and changes in the wind pattern would have a direct impact on deserts. Population growth and greater demand for land are serious obstacles in the effort to combat this problem.

Rise in temperatures may capitulate an increasing number of wildfires that makeover desert landscapes by ousting slow-growing trees and shrubs and succeeding them with fast-growing grasses. Irrigation used for agriculture may in the long term lead to spike in salt levels in the soil. That may not assist in plant growth. Grazing animals can ruin deserts' plants and animals. Off-road vehicles, when used irresponsibly, can cause irreparable damage to desert habitats. Oil and gas production may rattle sensitive habitats and nuclear waste may be abandoned in deserts, which have also been used as nuclear testing grounds as well as first and foremost choose options (Fig. 1).

4 Application of Remote Sensing and GIS in Climate Impact Analysis at the Regional Level

Remote sensing, combined with GIS is well known for the impetus of getting critical information from the disaster prone environment, this information can be easily shared with the government, NGOs and with the disaster prone areas for proper mitigation with an immediate effect. The study of Remote Sensing and GIS for acute climate change impact analysis to get a wide range of environmental data can be used to provide the government, and NGOs with veracity maps, demographic profile and

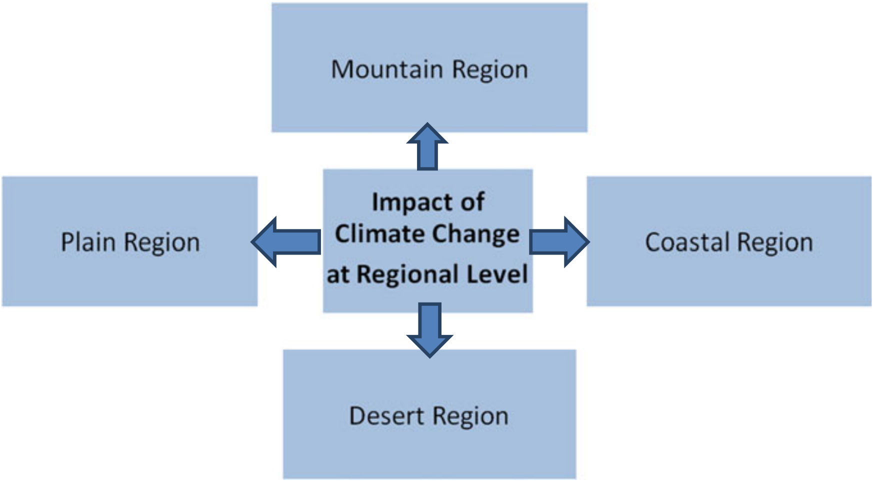

Fig. 1 Impact of climate change at regional level

agriculture practice which are very much advantageous not only for the government, NGOs but also with the stakeholders so they can provide necessary projects to help the local dwellers at the time of disasters.

In order to find out climate change impacts at regional level; such as mountainous region, coastal region, and plain region and desert region. Geoinformatic techniques in impact analysis are very much essential for effective disaster management through environmental change analysis model. By using satellite (DEM Model) data we can analysis the rate of glacial retreating, landslide detection, etc. Coastal sea level rise study technical and challenges stemming from the use of LiDAR, DEMs. Based on LiDAR error follows a normal distribution with 0 biases. Approaches to correcting discrepancies between vertical referring system or land and tidal datum transformation. LiDAR DEMs integrated into a GIS can be used to identify that are vulnerable to GSLR. Plain RS and GIS and multi criteria decision-making method. Desertification study can be done with the help of RS and GIS.

5 Disaster Policies and Practices for Resilient India

A set of policy actions out of researches, strategies, plans, legal norms and operating programmers should be reinforced in view of reducing the level of cumulative impacts and vulnerability in the disaster management context. At the behest of international policymaking bodies such as UN, ILO and International Food Organization, climate preventive policy and region specific approaches in collaboration with grassroots level activists for disaster resilient society are in urgent need. The United Nations Framework Convention on Climate Change (UNFCCC) approaches Climate risk reduction from two perspectives; first to mitigation or reduction of greenhouse gas emissions to stabilize concentration levels at a safe level by which global temperature rise may stabilize then the second perspective aims at adaptation, or adjustment to climate-driven change.

In conformity with the Intergovernmental Panel on Climate Change (IPCC), to keep global Warming below 2 °C, emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) must be halved by 2050 as compared with 1990 l levels. The long-term rather first and foremost objective as remedies to climate change is to stabilize hazardous atmospheric green house gas concentrations at a level that would stave off anthropogenic intervention with the climate system. Initiative to combat the climate change is very much essential and subsequently spike in temperature and results in issues such as ice or valley glacial melt, coastal inundation, desertification in plain and desert may have a minimal impact. Most of the policy is outdated and practices are old age in nature. An efficacious system for monitoring and impact assessment of policy implementation needs to be developed. Ensuring indulgence of stakeholder in the policy articulation is of vital importance. Effective management skill needs to be followed at grassroots level. In order to ensure adequate policy reinforcement the policies must include specifically detailed contingency Plans for coping with disasters along with guidelines on how such a plan is to be effectively made (Fig. 2).

The first and foremost policy should be on GHGs, to arrest the temperature rise. Some old age policies and practices should be revisited, reformation and implementation pertaining to finance, environment, education and society. The human rights issue is a matter of grave concerned in relation to disaster management, but the concern of human rights is also not duly addressed. It is necessary to develop coastal environment, legal institutes and socio-economic practices articulation and draft management plans, consult local people, implement pilot projects and viability

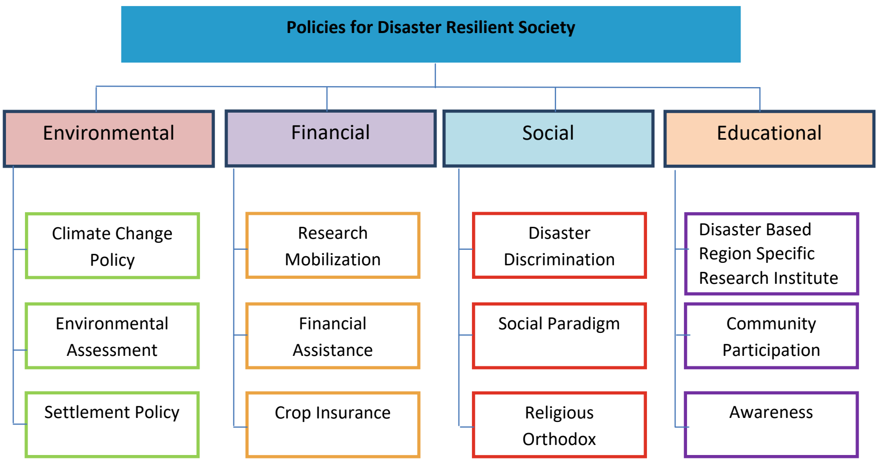

Fig. 2 Policies for disaster resilient society

studies and training in personnel forth projects. Most of the training development and awareness programmers are lacking in practical aspects of financial capacity and trained human resource.

6 Conclusion

The author, through some qualitative and quantitative analysis has found that acute climate change indicators are being felt more profoundly by being reflected through the irregularities in normal seasonal cycle. The author's observations on seasonal cycles especially in the coastal area of eastern India are quite astonishing. If there is a cyclone in the Bay of Bengal just before the onset of the Indian monsoon then there will be irregularities in the normal seasonal cycle and will interpret in the rest of the climatic phenomena. For example the Asian monsoon usually onset on the Malabar Coast by June 5 but, if there is a cyclone taking place then an erratic nature of monsoon will be reinforced. Subsequently other seasons would be an irregularity, a late monsoon early retreat of monsoon late winter, etc., indicate that climate change has direct impact on emerging disasters.

Apparently, Northern hemisphere experiences more heat owing to the dominance of landmasses and it has witnessed many warm years after 1990, since climate statistics have been monitored and documentation began in 1861 and it has also expected an increase in the global mean temperatures in coming years. Climate change is yet another threat to different landscapes such as mountainous, coastal belts and plains. Ice is melting, in coastal bastion inundation of flood owing to sea level rise and drought in the interior parts which suffer from water scarcity, etc. Adaptation to climate change is a challenge for all countries at the time of changing paradigm in acute climatic events. From a global perspective, the adaptation challenge is greatest for developing countries. They are more vulnerable to climate change because their economies are more dependent on climate-sensitive sectors, such as agriculture, fishing agriculture and food security deeply get threatened and keep habitants at stake in the era of climate change and hence some policies and practices at different levels need to be addressed for disaster mitigation. Coastal zone regulation is outdated and it needs to be revised and each responsible party, such as local-level and provincial-level officers and coastal communities should be involved in decision-making and formulating strategies and implication at grassroots level (Samaranayake 1995).

In this research article, all the individual factors of elements of weather have been analysed, so it can help managers to plan a better strategy for resilience during extreme events of climate for disaster resilient society.

A sustainable endeavour towards disasters resilient society, experienced and well trained administration are necessary to stay prepared against any impending disaster which may strike at any time and may destroy people, environment and economy. Looking at the above aforesaid illustration, undoubtedly new policies and practices are very much needed for disaster resilient society. The developing nation like India needs more concern on the disaster mitigation to save both its people and economy, but India being the second most populous nation in the globe lacks behind as per expectations and demand.

Notes

Climate Refugees are those people who lose their settlement and livelihood owing to sea level rise and marine transgression.

Disaster Discriminations If a person or a certain community on account of their cast, religion, greed, gender and socio-political ideology faces any discrimination at the time of mitigation, preparedness, rehabilitation and recovery in disaster management is called as Disaster Discrimination.

Natural disasters are those extreme events induced by nature that exceed the tolerable magnitude and make human adjustment very difficult, resulting in colossal loss of lives of human and animals, property, destruction of both natural and physical environment, (Sahoo and Satpathy 2020).

ILO—International Labor Organization.

IFO—International Food Organization.

Little Ice Age—AD 1550 to 1850.

UN—United Nations.

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Corporate Sector and Disaster Risk Management: A Critical Analysis with Reference to Corporate Social Responsibility in India

Vidhi Madaan Chadda and Navjeet Sidhu Kundal

Abstract The Companies Act, 2013 (Act) has ushered in the reforms for corporate administration, management and regulation in India. This law institutes a heralding reform through a provision mandating companies to contribute towards various avenues for enhancing societal well-being. The provision is set to catapult India into the league of countries considered as frontrunners in corporate social responsibility (CSR). The initial list of eligible activities for CSR spend did not mention 'disaster management' as an allowed expenditure. In 2019, the Ministry of Corporate Affairs, realising the huge potential corporate spending could have on disaster management, included the same into the list of CSR activities eligible under Schedule VII of the Act. More recently, the amendments in the CSR regime have changed the very nature of the CSR provisions from 'comply or explain' to 'comply or pay penalty' mandate. The amendments have introduced substantial changes to the CSR regime and are hailed as the game changer in India's business sustainability landscape. The present paper analyses emerging trends in India's mandatary CSR legal framework. It examines the CSR framework on its' conduciveness for disaster management generally and for building disaster risk resilience specifically. The paper argues for the adoption of a principled approach for devising CSR strategy to mitigate disaster risk and suggests policy and legal interventions for facilitating the same. It concludes with a suggestion, if the recent amendments are enforced effectively may turn out to be instrumental in making the CSR regime conducive for disaster risk reduction and building a resilient society.

Keywords Corporate social responsibility · Disaster management · Disaster resilience · The Companies Act · 2013

V. M. Chadda (✉)
TERI School of Advanced Studies, Delhi, India
e-mail: vidhim.chadda@terisas.ac.in

N. S. Kundal
Vivekananda Institute of Professional Studies, GGSIPU, Delhi, India

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1 Introduction

Advent of globalisation and consequential industrialisation and development has enhanced the risk of disasters and their hazards. The frequency and magnitude of disasters have increased manifold in the past few decades. With each passing year the disasters and their associated hazards are evolving (UNDRR 2020). The risk of disasters has further intensified with the emerging concerns due to climate change. Latest report by the Intergovernmental Panel on climate change proclaims that the human-induced climate change would lead to intense disasters in future (IPCC 2021).

The unprecedented year 2020 witnessed the onset of the COVID-19 pandemic. Undoubtedly, COVID-19 pandemic disrupted every facet of life worldwide. The current pandemic situation exposed a lack of preparedness on the part of nations worldwide to tackle this public health emergency. Even the developed nations miserably failed to tackle the pandemic situation effectively and consequently several pandemic waves led to COVID related illnesses and deaths. During the ongoing pandemic itself the world including India were faced with extreme climate events like floods, wildfires, droughts and cyclones.

Proliferation of multinational corporations also owes their genesis to globalisation. These corporations as contribute to a host of extreme climatic events like green-house gas emissions, global warming and climate change. While corporations by their operations contribute to these problems, they in turn also get adversely impacted by climate-induced disruptions such as floods, cyclones and landslides. This leads us to a consequential understanding that responsibility for disaster risk management and disaster risk must be shouldered by the corporations as well.

Moreover, the reports confirm India being vulnerable to natural hazards like floods, earthquakes, droughts, landslides, etc. To quote, India is the third most disaster-prone country in the world and owing to the density of its population, it becomes even more vulnerable to such disasters (UNDRR 2020).

Contemporary disaster response suggests a diverse range of partners including local community, researchers, scientific experts, government agencies at all levels, civil society organisations, international donor community and corporate sector (Asian Disaster Preparedness 2004). As the intensity and frequency of the disasters multiplies, need for a concerted global action becomes critical. Role of corporate sector in the backdrop of its competitive advantage and capacities can not be undermined. International Decade for Natural Disaster Reduction called upon all governments to assume the primary responsibility to formulate national disaster mitigation programmes and other policies which would reduce the consequences of natural disasters. The same resolution also stressed upon the need for governments to partner with private sector, civil society organisations and other UN agencies (General Assembly resolution 44/236).

India has undertaken several measures for promoting a holistic approach for strategising disaster risk reduction and building community resilience. Towards this end, India adopted the Sendai framework for disaster risk reduction 2015–20 and is working for effective implementation of the Sustainable development goals 2015–30.

For effective attainment of goals and implementation of strategies, Indian governments will have to develop meaningful partnership with the companies who possess the potential of playing a significant. Understanding this very well, the legislators introduced the concept of mandatory corporate social responsibility through a law. This provision required large companies to engage in philanthropic spendings in the pre-defined areas, quantity and manner. While introducing the mandatory CSR regime in India, the legislators justified the said move by noting the following;

'It is a well-perpetuated fallacy that corporates are run on the promoters' or shareholders' funds alone. The fact of the matter is that most of the capital required by corporate—both long-term and medium term is provided by the banking/financial system, which is operated out of the public funds. Therefore, if corporates are mandated to undertake CSR, it is very fair and logical and a natural corollary of the nature of capital invested in them. It need not be over-stated that the corporate owes it to the people and the society to pay them back in terms of social services and by building social capital for common good. This cannot be the sole responsibility of Governments' (The Companies Bill 2011).

The present paper focuses on the role of corporate sector on disaster risk reduction and management. The paper analyses emerging trends in India's mandatary CSR legal framework. It further examines the CSR framework on its' conduciveness for disaster management generally and for building disaster risk resilience specifically.

2 Role of Corporate Sector and Disaster Risk Reduction and Management

For a long time, the corporate sector was viewed in isolation and not perceived as an entity from the standpoint of the societal goals. However, the developments in the last few decades have led to a complete overhaul to this perception. Today companies are central to any societal discourse. In the present times, it is well accepted that the existence of the corporate sector is inherently intertwined with the communities' well-being and safety. In fact, the corporate sector and society are mutually dependent on their existence, development and prosperity (Ministry of Home Affairs 2012).

Disasters have a huge impact on corporates as well. Recent report suggests that over the last twenty years disasters led to approximately US $ 2.97 trillion in economic losses worldwide (UNDRR 2020). Even the initial data set asserts that around 85% of the total insurance cost is from natural disasters and of which more than half have incurred losses (World Bank 2002). With such a magnitude of disaster risk, the corporate sector becomes perennially faced with concerns over safety of operations and its' sustenance. With the advent of globalisation, corporations are increasingly spreading their operations beyond their territorial bounds. Transnational corporations prefer developing and under-developed nations as preferred destinations to operate due to cheap labour and other resources. This trend makes these companies susceptible to hazards and face concerns of potential disasters (Twigg 2001). It thus becomes imperative for any company, whether domestic or multinational to take necessary actions for disaster risk mitigation (Miyaguchi and Shaw 2007).

The corporate sector enjoys enormous resources in terms of human, financial and technical. Further, owing to their operations, corporations have to closely work with several stakeholders this makes their own growth dependent upon the well-being, security and resilience of the society. Role of corporate sector becomes even more critical in case of developing countries in terms of contribution of nation building as well as post-disaster relief. This role is emphasised as the corporates possess capacity to safeguard themselves but also to protect the community against natural calamities and reduce vulnerability due to potential disasters (Issar and Mathur 2005).

Indian companies have contributed commendably in the past during disaster relief, rehabilitation and reconstruction activities. They played a significant role post the devastating earthquake in Gujarat in 2002 and even post the 1999 cyclone in Orissa (Ministry of Home Affairs 2012). Indian confederation of Industry, chambers of commerce and other regional associations have in the past joined hands with the government in the times of distress and taken progressive steps towards disaster risk reduction.

Although it is pertinent to point out here that the corporate response to any calamity is excessively post-disaster centric. A Conrad N. Hilton Foundation Report pointed out that in the United States about two-thirds of the corporate monetary assistance occurs within the first two months of post a disaster strikes and its completely stops post five to six months of the occurrence of the disaster (Paton 2012). Corporate contribution in the aftermath of a disaster can not be undermined. It undoubtedly strengthens the efforts of the government directed towards recovery. However, corporates have not worked towards disaster risk reduction or building resilient communities. Much may be attributed to the psychological pattern of reactive giving as human instinct is to respond to proximate causes and support immediate suffering (Common Impact 2019). Skewed corporate expenditure on preparedness and risk mitigation may also be due to the reason that such efforts require longer and sustained allocation of resources that too on an enormous scale. Another convincing argument may also be that relief and rehabilitation initiatives attract media attention and hence helps the company to enhance its image. This remains by far one of the major challenges in corporate spending for disaster risk management, that the corporate sector remains less attracted to interventions for disaster mitigation and risk reduction (Seeds India 2002).

Study by the Centre for Disaster Philanthropy strengthens this assertion as well. It says that only 1% of the corporate sector contribution on the disaster in the United States is spent for disaster preparedness and merely 0.8% is directed towards resilience and risk reduction (Common Impact 2019).

Indian government too has raised this concern and recommends for the involvement of the corporate sector in disaster preparedness and mitigation planning through a streamline framework of sensitisation, training and strengthening response mechanisms (National Disaster Management Framework, Ministry of Home Affairs 2012). On similar line, UNDP-Government of India programme also stresses the need for the promotion of public–private partnerships and pushing the agenda for enhanced awareness and sensitisation.

3 Legal Evolution of Corporate Social Responsibility and the Companies Act, 2013

Corporate Social Responsibility is neither novel nor radical concept for India. The principle underpinning CSR is that the corporations are responsible to society over and above their object of profit maximisation. This principle has roots in ancient Indian literature and is premised upon religious beliefs, culture, ethics and value system. This value system and beliefs are increasingly imbibed in the present-day management philosophy. Indeed, the ancient scriptures provide a rich source for theoretical context that could be helpful in modern management world (Datta et al. 2018). Indian corporates, for long, have been carrying out philanthropic endeavours in one or other way. Here, the philanthropic ideologies and initiatives were considered obligatory owing to religious responsibilities integrated with stakeholder engagement (Sunder 2013). It is believed that the history of CSR in India runs parallel to the historical advancements in the country (Rishi and Moghe 2013).

The initial discourse on CSR was premised upon the idea of voluntarism as maximisation of shareholders' wealth was considered as the prime object of business. With the advent of globalisation and rapid expansion of corporations beyond their territorial bounds, this idea of profit or wealth maximisation also metamorphosised (Tripathi 2020). Companies increasingly became mindful of their social behaviour and image. Lately, there has been a growing consensus as to assessing corporates on the basis of their capability to contribute to societal well-being (Common Impact 2019).

Indian legislature and policymakers swiftly responded to this shift by rolling out with a voluntary guideline on CSR in 2009. The voluntary guidelines were fine-tuned in 2011. The enactment of the Companies Act, 2013 (Act) ushered in the new dawn for corporate regulation in the country. The Act institutionalised corporate philanthropic giving by introducing a mandatory provision for CSR. The legislators re-defined the business-society relationship vide this pathbreaking move (Bergman 2019). Until the enactment of 2013 Act, CSR remained voluntary in nature.

CSR provision contained in Section 135 of the Act, required companies above a specified threshold to contribute on yearly basis, at least two per cent of their average net profits of the company made during the three immediately preceding financial years. Such companies are required to constitute a CSR committee comprising of directors to be responsible for carrying out all the CSR-related activities of the company. The relevant part of the provision is reproduced for clarity:

'Every company having net worth of rupees five hundred crore or more, or turnover of rupees one thousand crore or more or a net profit of rupees five crore or more during the immediately preceding financial year shall constitute a Corporate Social

Responsibility Committee of the Board consisting of three or more Directors, out of which at least one director shall be an independent director.' (Section 135(1) The Companies Act 2013).

'The Board of every company referred to in sub-section (1), shall ensure that the company spends, in every financial year, at least two per cent. of the average net profits of the company made during the three immediately preceding financial years or where the company has not completed the period of three financial years since its incorporation, during such immediately preceding financial years, in pursuance of its Corporate Social Responsibility Policy.' (Section 135(5) The Companies Act, 2013).

CSR Committee so constituted is entrusted with the obligation of formalisation and monitoring of CSR policy. CSR policy is required to indicate the activities to be undertaken by the company along with the details of expenditure to be incurred on such activities. This CSR policy is then recommended to the Board of Directors (Section 135(3) The Companies Act, 2013). CSR policy besides indicating the activities and expenditure, also reflects on the action plan encompassing the approach and direction guiding the board of the company for the selection, implementation and monitoring of the activities (Rule 2(1) f, The Companies (Corporate Social Responsibility Policy) Rules, 2014).

The Act also specifies as to what constitutes CSR activity for the said purposes. A suggestive list of activities is provided under Schedule VII of the Act. Most of the entries in the Schedule are crafted around areas of; a. social welfare with a key focus on education, health, rural and development; the upliftment of marginalised groups with a key focus on eradicating poverty, hunger, women empowerment, disabled, etc.; environmental sustainability; and nation building with a key focus of protection of art, culture and heritage, the welfare of armed forces veterans, promotion of sports (Schedule VII the Companies Act 2013). Since the very inception of the CSR clause, the concerned department of the government has emphasised that the list of activities enumerated under the Schedule has to be construed liberally and the list to be perceived as recommendatory in nature (Ministry of Corporate Affairs 2015; 2019; Circular dated 18 Jun 2018). The report of the high-level committee on CSR also suggested for adding an 'omnibus clause' to the list for accommodating any developmental concerns, needs and priority areas (Ministry of Corporate Affairs 2015). Later, the committee recommendations of 2019 also emphasised on the need to have a holistic view and implications of the activities mentioned for CSR and suggested the government may consider earmarking certain areas in the list as a priority by issuing directions in this regard (Ministry of Corporate Affairs 2019). Such inclusions would induce flexibility in the current CSR mandate which is at various instances regarded as rigid in its approach and implementation (Kamalnath 2021).

Section 135, Schedule VII of the Act read along with the CSR Rules provide for the framework of conceptualisation, execution, implementation and monitoring of CSR policy by the companies. The board of directors is entrusted with the obligation for compliance of CSR policy under this CSR framework. Some argue that as the implementation of CSR has been made under the law as a board's compliance it has to be perceived as within the company's corporate governance (Afsharipour 2018).

3.1 Recent Changes to CSR Law and Its' Conduciveness for Disaster Risk Reduction and Building Resilience

The government has been quite responsive towards the needs of India Inc. as far as the adoption and implementation of CSR policy is concerned. CSR framework has been fine-tuned on several occasions in the past to address the challenges faced by the corporate sector. In the short span of six years, the Indian CSR provision has undergone two major amendments, few clarifications have been issued to resolve implementation issues and two high-level committees have given their recommendations to analyse the implications of the provision (Ministry of Corporate Affairs 2015, 2019).

Even during the current pandemic situation, CSR provision was amendment to facilitate the pharmaceutical companies involved in research and development of COVID-19 vaccine or medical devices. These companies could claim exemption even for the spending they made on research and development in the 'normal course of business' (Ministry of Corporate Affairs Notification dated 24 Aug 2020).

In spite of the Indian companies having a tradition of philanthropic giving, and the introduction of mandatory CSR law, the contribution of the corporate sector to disaster risk reduction is negligible. CSR to build disaster resilience is the least developed concept, especially in relation to India. Most of the contributions made by companies do not effectively address disaster risk reduction and building resilience (UNDRR 2020). Most of the CSR spendings have remained in areas like health and education (National CSR Portal National CSR Portal) and barely two per cent has been spent towards disaster management or relief (Gupta 2021).

Recognising this gap in CSR spending, the Ministry of Corporate Affairs added 'disaster management, including relief, rehabilitation and reconstruction activities' to Schedule VII for encouraging Indian companies to spend towards disaster relief and rehabilitation (Ministry of Corporate Affairs Notification dated 30 May 2019).

Recently, a major overhaul of CSR provision was initiated vide the Companies (Amendment) Act, 2020. These amendments are set to foster accountability and transparency into the present CSR regime and are lauded by the stakeholders as gamechanger (Rishi and Antani 2021). The amendments not only cause a significant shift in the fundamental features of the CSR policy, it also widens the scope and ambit of the definition of CSR. One of the major changes has been to make the CSR regime as a 'comply or pay penalty' as against the erstwhile requirement of 'comply or explain.' The provision now directs the non-compliant companies and their officers to pay penalty in case there exists any default in carrying out CSR obligations (Section 135(7) the Companies Act, 2013). Though since the beginning the CSR provision was seen as mandatory in nature by many (Dharmapala and

Khanna 2018), however, in case of non-compliance the company was only required to explain the reasons in their annual report. For this reason, India's model was described as quasi-mandatory as the companies were required to spend on CSR but were given the flexibility to explain and justify in case of non-compliance. Their existed flexibility as regards the expenditure; however, disclosure was mandatory (Varottil 2018). The recent change of bringing a penal sanction takes away this flexibility.

Another important change has been to let the companies carry forward their unspent CSR amount in case of any ongoing project and transfer the said amount in a special account within thirty days from the end of the financial year (Section 135(6) of the Companies Ct 2013). The unspent CSR amount can be carried forward for a period of three subsequent financial years (CSR Rules 2014).

A significant change towards the implementation of CSR policy has been the following:

- Mandatory registration of implementation agencies with the ministry of corporate affairs. Now the companies can only implement their CSR policy through the implementation agencies/civil society partners. The rules do not define 'implementation agencies' but in common parlance they constitute civil society partners, NGOs, etc.
- Every company having an average CSR obligation of ten crore rupees or more is required to undertake an impact assessment of their CSR projects through an independent agency (Rule 8 CSR Rules 2014).
- Companies are allowed to engage international organisations for the purposes of designing, monitoring and evaluation of CSR projects.
- Board of directors have been entrusted with an obligation to draw detailed annual action plans for undertaking CSR programmes, certify CSR reports and place the details related to CSR committee and policy on companies' website for public access.

This shift in policy for regulation CSR seems to be far reaching and possesses potential for positive outcomes. As far as the implications of recent changes on disaster risk reduction and management are concerned, they are encouraging too. The provision allowing the companies to carry forward their unspent CSR amount will facilitate companies to take up long-term projects. This may drive the Indian companies towards projects focused on building community resilience towards disasters. Further, allowance to the companies for engaging international organisation in formulation and monitoring the projects and programmes will also assist companies in collaborating with UN agencies and other such organisations of repute. Measures like impact assessment and enhanced disclosures have given a loud and clear message to the Indian corporate sector to view CSR as a continuous sustained activity rather than an ad-hoc event. All these changes along with the inclusion of 'disaster management relief rehabilitation' as a qualified CSR spent have a bright future in terms of attracting corporates towards disaster spending. However, how these changes unfold is the test of time. Probably, CSR reports of the following years will assist the future researches to evaluate the efficacy of the recent amendments and highlight underlying pain-points.

4 Integrating Corporate Social Responsibility in Corporate Strategy—A Proposal

The idea of responsible business is embedded in the principle of accountability of businesses towards all its stakeholders. In the backdrop of the recent changes in the legal landscape for regulating corporates in India, it is clear that the business must proactively shoulder the load with the State for attainment of broader societal obligation. Lately, the legislators are meticulously devising and streamlining the framework for responsible-business paradigm. This framework covers both, policy and legislative and compliance mechanisms for augmenting the conduct of business in a sustainable manner. The idea of making the company and its' directors to bear wider responsibility of not only their shareholders but towards their stakeholders as well was first embedded in the National Voluntary Guidelines on Social, Environmental and Economic Responsibilities of Business. (Ministry of Corporate Affairs 2011). The essence of the voluntary guidelines was then incorporated into the Companies Act, 2013. Later the securities market regulator of the country as well, has affirmed for bringing sustainability reporting at par with the financial reporting requirements of the company (Securities Exchange Board of India 2021). Mandating CSR, strengthening sustainability reporting procedures and evolving Environmental Social Governance norms, evidence the incremental steps towards the emerging business sustainability regime in India (Ministry of Corporate Affairs 2020).

In the given situation, it now becomes incumbent upon the companies to take up CSR and other sustainability initiatives as a strategic intervention. Further, the aim must be to align these activities with the vision and mission of the company. This alignment would entail engaging stakeholders, involving community groups and non-governmental organization for deeply understanding the societal needs (Datta et al. 2018). Researchers suggest for a positive correlation between CSR and corporate reputation whereby a socially responsible company enjoys a strong brand image and is able to attract consumers for a long-term, strengthen competitive advantage, avoid activists boycotts and rigorous regulations of the government (Freeman 1984; Elkington 1998; Prahalad; 2007; Bartlett 2008) Being socially responsible also has a positive impact on the workforce by encouraging staff loyalty and commitment (Centre for Social Markets 2003). A good illustration of this would be Tata, which has created a brand image and goodwill among its' stakeholders primarily due to institutionalisation and mainstreaming of CSR, engaging in community development and nation building activities (Mitra 2011). Hence, companies will have to decide if they would want to integrate CSR and sustainability initiatives in their value chain in order to create a long-term strategic value creation for their entity. The critical question each company needs to ask is; Whether CSR expenditure be treated as CSR spending or CSR investment?

As India gears up to meet its net zero emission targets as committed in the recent United Nations Climate Change Conference, 2021 (COP 26) held at Glasgow, United Kingdom, meaningful partnership with the corporate sector is a *sine qua non*. Wherein, the role of wholesome framework of business sustainability encompassing CSR, ESG and sustainability reporting cannot be undermined.

5 Contemporary Challenges and Prospects for CSR

Natural hazards and adverse climate events continued during the present health emergency as well. Since the onset of the COVID-19 pandemic, India witnessed a series of natural disasters including major cyclones, floods, locust attacks, landslides exposing the already vulnerable people at risk (Cord and Arnold 2020). With its adverse impact on the countries across the globe, the pandemic initially seemed to be a great leveller. However, as the time passes it has distinct implications on the vulnerable population owing to social inequalities like wealth, gender, age and caste.

The present approach for disaster management and building risk resilience still counts on the out-dated response mechanisms informed upon assumptions based on historical data analysis. In the current times, the world is witnessing new-age disaster events owing to factors like climate change, the pattern of even the disasters has also evolved. The said complex nature of the present-day disasters call for a more comprehensive response aimed at building community resilience and cannot be a one-time intervention or a band-aid solution (Gupta 2021). For instance, India's response to the pandemic-disaster situation was largely premised upon the Epidemic Diseases Act, 1897-an age-old-colonial era legislation. By relying upon the colonial law to deal with the challenges of the present times, the country failed to provide a modern legal framework to tackle the public health emergency. Whereby, a pressing need is felt to replace the old law and replace it with a robust legal regime focussing on a right-based and public health-oriented approach (Goyal 2020).

Secondly, rationalising the role and participation of the private sector and other non-governmental authorities in partnering with the governments also becomes crucial. A recent report of the United Nations Office for Disaster Risk Reduction while pointing out climate change as the primary reason for the surge in natural disasters in the past two decades, flags the inadequacies on the part of the governments in preventing the climate hazards. This report presses for a systemic and a multi-hazard approach towards disaster risk reduction for the ever-evolving, globalised and interconnected world. Another suggestion has been to strengthen the disaster risk-governance for advancing clarity in vision, competency, coherence, coordination and effective implementation of the disaster risk management plans. The report recommends for public and private investment for disaster risk prevention and reduction in order to create disaster resilient societies (UNDRR 2020). Meaningful public—private partnerships is the way forward for engaging with the communities, assessing climate risks and for identification of socially inclusive solutions that are customised to local needs.

Besides, streamlining the legal framework and strengthening public–private partnership another important requirement for building resilience is to significantly invest in long-term solutions. Augmenting public infrastructure, enhancing access to financial instruments, building capacities, taking anticipatory actions are all necessary for building resilience. Governments have to acknowledge the role of business community and civil society members in meeting such challenges by deploying their competitive advantage.

Moreover, challenges and opportunities for India are unique in the backdrop of its' huge population, extreme diversities and potential hazards. This demands for a joint, shared and effective participation of corporates which is not mere consultative but pro-active. Enormous untapped potential of corporate sector towards enhancing resilience need not be stressed more. Indian corporates have been following a rich tradition of giving, worked towards the well-being of the society and considered themselves integral to the society. Ancient Indian literation too, substantiates this fact (Maniapam and Dass 2008). The legal landscape of corporate spending and social responsibility has been evolving over the past years. However, not much has changed been witnessed in its basic trends for spending. Until lately CSR has been propelled by philanthropy through charitable donations and diverted to community development initiatives in health and education. Thus, making CSR approach marred with a lack of transparency, intermittent spendings and non-existent standardisation (Jamali and Mirshak 2007). Scholars have even critiqued Indian corporate responsibility for being in a confused state (Chahoud Emmerling et al. 2007).

The Companies Act, 2013 institutionalising the regime for mandatory CSR in the country has received mixed reviews. It is viewed as a forward-looking provision aimed at enhancing transparency and self-regulation of corporates. The moot question remains; will it resolve the confused state of India CSR? (Jamali et al. 2015). Setting up of high-powered committees, various amendments, clarifications evidence governments' intention to iron-out implementation issues and facilitate India Inc. for effective compliance.

It has been highlighted in the previous sections that the corporate contribution to disaster risk reduction and building resilience has been negligible. Recent government initiatives and amendments aim to streamline CSR activities, infuse ease of CSR spending and compliance requirements. These interventions may promote equitable CSR spending across activities mentioned under Schedule VII in the future. Even the inclusion of 'disaster management' as an eligible CSR activity has been recent and it will take a few years to assess its' implications. There still exists a need to exemplify how CSR interventions can include disaster relief activities. This requires the inclusion of the suggestions as made in this paper to corporates' CSR policy (Dave 2000).

Latest government mandates have clarified that no longer CSR investments be perceived and carried out as a one-time affair. Corporates will have to integrate their CSR policy in the corporate agenda for effective implementation. This may ensure that the CSR funds are invested in such a manner so as to meet the sustainable development goals directly and the aim of disaster resilience tacitly (Kanji et al. 2020).

6 Way Forward

Attaining business sustainability remains one of the major challenges for the attainment of sustainability agenda. Emerging legal landscape for CSR in India pushes for a transition from CSR to strategic CSR. CSR thus far has been a 'living law' where in to facilitate effective adoption by the companies' changes have been made from time-to-time.

This paper has attempted to analyse the legal evolution of CSR with respect to its' conduciveness for disaster risk reduction. Paper gives out certain theoretical suggestions for the effective attainment of the said objective. As the changes to the CSR law are recent, much of the future discourse will be dependent upon the execution and implementation in the future.

Companies for sure, have to rethink, reimagine, redesign and realign their business strategies if they aim to effectively partner with the governments in building a sustainable and disaster-resilient society. CSR has the potential to act as an effective tool towards this endeavour. There exists merit in pushing the case for CSR for disaster risk reduction. However, much will depend upon the efficacious implementation of the recent amendments to the CSR regime.

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Impact of Training and Awareness Programmes of Community Volunteers in Disaster Risk Reduction and Response—A Study of Srinagar City

Bilquees Dar and Sajad Nabi Dar

Abstract Communities are the pool for knowledge, experience and capacities to deal with disasters and this is the main factor that helps in building resilience, the study was conducted in Srinagar city which is a multi-hazard-prone area of Jammu and Kashmir. The study aims to understand the impact of awareness and training of community volunteers in the district. The study also focussed on chalking out the resource pooling of community volunteers and skilled volunteers in the city. A qualitative study was conducted by interview method of 300 trained community volunteers in the city, the sample for the study was selected by using purposive random sampling. The results of the study revealed that 80% of the sample was trained more than twice and the rest have received the training at least once. The study showed that 45% of trained community volunteers lack the possession of emergency kits which leads to the hindrance in proper response to the disaster events. The study also revealed that after training the community volunteers, they developed various innovative ways based on their training and inherent skills to reducing the risks and respond to the disasters. But, these community-based methods of Disaster risk reduction and response are very uncommonly scaled out and are not either systematically included in disaster management policies and practices. For the analysis of community preparedness, the National centre for disaster preparedness (NCDP) model was used.

Keywords Vulnerability · Resilience · Community volunteers · National centre for disaster preparedness (NCDP)

B. Dar
School of Management Studies, Desh Bhaghat University, Amloh Road, Mandi Gobind Garh, Fatehgarh Sahib, Punjab, India

S. N. Dar (✉)
School of Humanities, Lovely Professional University, Phagwara, Jalandhar, Punjab, India
e-mail: sajadsch1@gmail.com

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1 Introduction

Community is described as a sense of belongingness and togetherness that members have, it is an emotional assurance that the people who are part of the community are important to one another and the group, and it is also a common belief that the needs of the community members will be met through their promise to stay together. So, the word community is reassurance or commitment of understanding, supporting and helping each other (Chavis et al. 1986). While as Resilience can be understood as the ability to cope and emerge out of disaster risk. It can also be described as the capacity, skills and resources available to Prepare, mitigate, resist and recover from disasters. Resilience can be described as the idea of dealing with adaptive behaviour and learning in socio-ecological systems of disasters, with a main focus on responses, nonlinearity, volatility and disturbing events. The second concept of resilience focuses on the identification and development of community strengths, and building resilience with prime focus on developing people—knowledge and learning, connections with place, beliefs and, values, social integration, joint governance, broadening economic conditions, infrastructure of the area, leadership qualities, and outlook. So, the concept of resilience can be better understood as an integrative approach ingrained in the concept of social ecology of disasters which can include the identification of inherent social strengths and integration into a particular area. (Berkes and Ross 2013) Lack of a proper Disaster management mechanism imposes many questions on the capability of the government and non-governmental agencies to plan for, deal with and respond to disasters. Thus, it is of utmost importance that communities which are vulnerable to potential disasters should work on strengthening their resilience to natural as well as manmade disasters in order to be able to have a proper recovery mechanism which in turn will help them to safeguard or minimise the losses that can occur by disasters. Capacity Building particularly aftermath of a disaster, can help in short-term and long-term community recovery. In order to imply Capacity building and community resilience, proper awareness and understanding of the resilience capability of the community is significantly important. A clear and apt understanding of the inherent resilience capabilities can be done by assessment of strengths, vulnerabilities and risks of the community so that a proper capacity-building approach can be implemented within the community which will enhance the strengths and reduces the risks and vulnerability of the particular community. While a number of conceptual frameworks are already available for the assessment of the resilience level of communities to disasters, but these differ on their prominence, scope and definition of community resilience and how it should be properly and accurately assessed. The role of certain factors like environmental factors, social integration and networks, administration, infrastructure and economic attributes associated with community resilience should always be taken into consideration while assessment of community resilience (Saja et al. 2021).

1.1 Resilience and Recovery

When disasters occur communication within community and social integration is a major contributing factor for the improvement of the resilience of households (Ghanem 2016) conducted meta-research where studied, he came up with 5 elements. These 5 elements are attaining a safety sense, self-calming ability, realisation of collective efficacy and the way of achieving the articulated goals of society, Liaison with the resources and people and re-framing a sense of hope within the community, these 5 elements are both a contributor and a result of resilience.

Though the concept of resilience is thought to be a genetic component in people but in real sense it is a phenomenon that involves each person of a community, families from a locality and communities altogether. Resilience can be ingrained and established (Honda 2013) on the individual basis, one of the form of resilience is cognitive—the capability to understand what will happen during and after a disaster in a particular area, the ability to be efficient, and to finally be able to attain an understanding of the impact of the disaster. The cognitive resilience can be promoted in many ways like you are providing information to someone, you are talking with other people, and like you are telling stories and at the same time you are setting goal. Resilience can be considered as the capability to develop attachments. The department of Social Determinants of Mental Health of world health organisation in 2014 has demonstrated that attachments play an important role in mediating when people experience any disasters. The attachment resilience in connection with the disaster incorporates an internal process and being able to understand how a person adopts a new situation and how it sustains. This description of adaptation and sustaining stories inspire the people at the same time it develops an ability to form a bond of meaningful and affectionate relationships with other people Rashid and Seligman (2018). Resilience incorporates structural factors like concrete resources, political leadership and non-structural factors like an ethic of caring, interethnic harmony apart from that formal and informal social networks (Linkov et al. 2014) the important structural factors which contribute to nurturing resilience are social justice, local people empowerment and communities respecting and dignifying heterogeneity within the community and investing in social capital Gil-Rivas and Kilmer (2016). Unique interface of factors within the social ecology of communities can lead to vulnerability of a community but also be a reason for generation of resilience within the society. Resilience is actually a process from to an individual and from a community (Betancourt and Khan 2008). Pescaroli and Alexander suggested while discussing disasters and reducing the vulnerability of a community that factors at the bottom level of organisational scale may help in developing the resilience of larger systems by producing positive feedback. In complex disasters, there are chances of positive feedback loops that can lead to an increase in contextual resilience (Alexander 2000). For instance, when society has a trust on their leaders and believes that their leaders care for them; the survivors may develop a greater sense of personal efficiency, positivity and will be hopeful. The standard family therapy practices that strengthen family resilience are helping them to improve communication within the family members, specify the roles, and outline boundaries (Walsh 2004). The disasters place strains on families and decrease the proper family functioning, whereas when a family adapts to the changed reality and adheres to the mutual connection that is a form of family resilience (Patterson 2002).

1.2 Disaster Risk Reduction

The impacts of disasters include both loss of life as well as damage to infrastructure besides the social, economic and environmental consequences that are complex. Thus, there is a need for strategic as well as innovative strategies to manage the impacts. Disaster Risk Reduction is a well-designed approach and a proper way to manage disaster risks (Diallo 2019) while a flexible and learning-based process through a multi-stakeholder partnership is considered as an alternative approach for governing complex problems like disasters. Disaster Risk Reduction can be defined as an integrative measure which needs to be incorporated into development to assess and control the causal factors of a disaster. DRR includes reducing the exposure to hazards and disasters, decreasing the vulnerability of locals, effective land management practices and better preparedness for catastrophes.

Capacity building has proven to be the best option for decreasing global losses to a considerable extent but in the meantime has become a challenge for external agencies to support the development of sustainable capacities for disaster risk reduction in disaster-prone countries (Brebbia et al. 2011) Multi-Stakeholder partnership and co-ordination plays a pivotal role in Disaster risk reduction so the Stakeholders involved in forecasting, preventing, managing and mitigating disaster risk should be in collaboration while working on Disaster Risk Reduction. Creating such awareness will help citizens better understand the risks and exposure they might be having to a disaster and ultimately prepare them for better response and protecting themselves against disasters.

For increasing the level of Community resilience community members need to be part of the Disaster response teams, and need to be motivated and trained for effective response, reuse and self-protection. Disaster risk assessment and mitigation are primarily basis on the proper community awareness about the risks and preparedness and prevention measures but unfortunately this component of awareness is missing in the communities. Therefore, it is very important to increase awareness of the (i) Risks of the area to which the community belongs (ii) intensity and frequency of the events that are likely to occur in the area; (iii) possible consequences of disasters which are likely to happen in the area on individuals and the community as a whole.

2 Area of Study

Srinagar city is located between 33° 53’ 49′ to 34° 17’ 14′ N latitudes and 74° 36’ 16′ to 75° 01’ 26′ E longitudes (Fig. 1) and is 5200 feet above sea level. The city is spread in an area of 294 km^2 and is located on both the banks of the famous Jhelum river is locally called as vyth. The rivers pass through the city and meander through the valley, moving onward and deepening in the Dal Lake. There are nine famous bridges in the city which are connecting both parts of the city separated by the river Jhelum.

The Inhabitants of the city are vulnerable to natural and human-made hazards/disasters including earthquakes, wildfires, floods, and landslides. In addition to that communities are directly affected by extreme levels of conflict, winter fires, road accidents, etc. (State disaster management plan 2016). The UT of Jammu and Kashmir is falling the earth quick zone IV and Srinagar as an urban area are more vulnerable to the earthquake which has been already seen in 2005 earthquake created destruction of property and loss of human life not only this the whole Srinagar city is laying on the flood plains of Jhelum River and offend get flood with a slight rise of water level in Jhelum River. The biggest flood has seen in the year 2014 in which the whole city get submerged in the water and created the loss of life and property of crores (Fig. 2).

The expansion of the urban population in the area is creating more problems for the city it is choking all the outlets of the streams and flood channels. Apart from

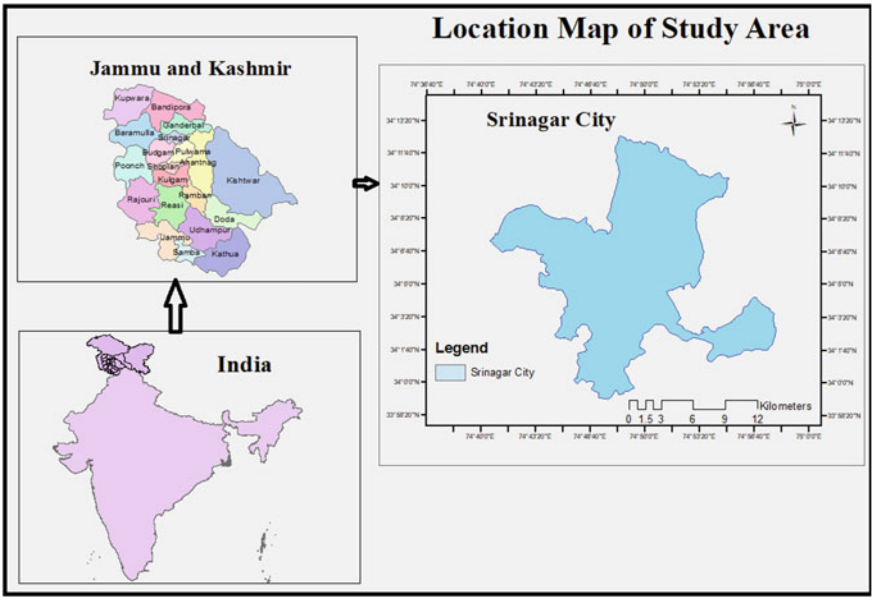


Fig. 1 Location map of study area

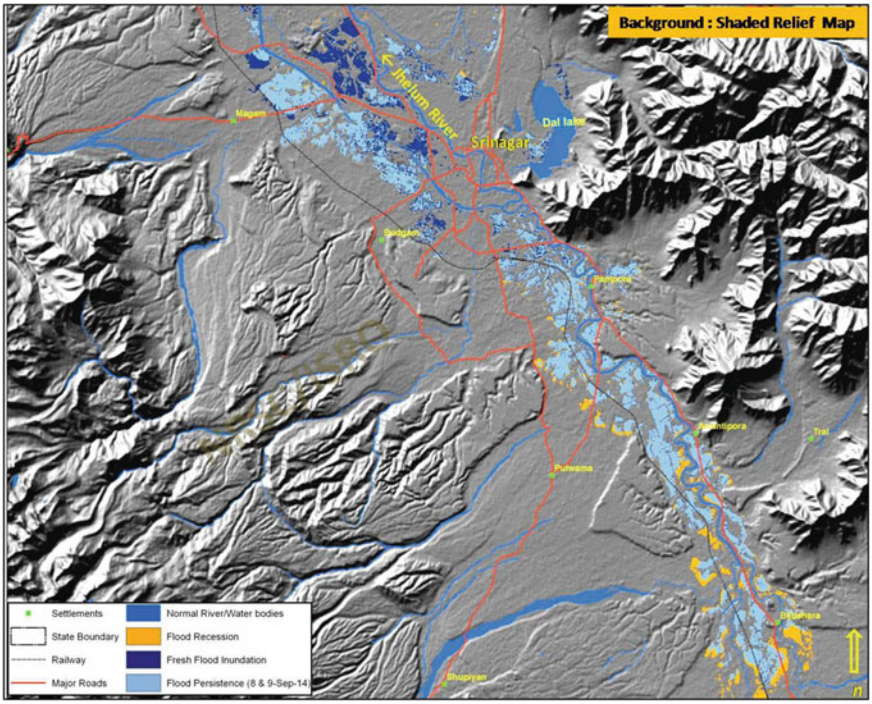


Fig. 2 Area under flood water 2014 (*Source* National Remote Sensing Center Hyderabad 2014)

that the presence of the mountain range near the city also creates the disaster like a landslide and the forest fire in this area. The city also remains politically active and often gets affected by the violence and creates trouble to the residence of the area not only the loss of life and property but also affected the mental capability of the people.

3 Aims and Objectives

The study aimed to understand the impact of awareness and training of community volunteers in the district. The study also focussed on chalking out the resource pooling of community volunteers and the skilled volunteers in the city.

4 Database and Methodology

The data used in the present study were collected from both primary and secondary sources. To find out the impact of the level of awareness and training primary data was collected from 300 respondents of Srinagar city through a random sampling technique with the help of a semi-structured questionnaire.

The semi-structured interview questionnaire guide was created based on "5 Action Steps to Personal Preparedness" derived from the NCDP model (National Centre of Disaster Preparedness, Earth Science Institute, Columbia University).

The interviews explored five main topics:

(1) Awareness of Risks in the surroundings
(2) Community Involvement in disaster preparedness
(3) Communications within the stakeholders and community members
(4) Training received by community volunteers
(5) Possession of Disaster Management Kits with the trained volunteers.

Secondary data was collected from the Resource inventory of the District Disaster management plan of Srinagar. Besides various reports, research papers, articles, journals were consulted to gauge out the objectives, the collected data was analysed with the help Risk assessment scale and likert scale and some statistical techniques and the results were presented in the form of Tables and Charts.

5 Results and Discussion

Communities are the pool for knowledge, experience and capacities to deal with disasters and this is the main factor that helps in building resilience. Training of the Community Volunteers is a prime important step in Disaster Risk Reduction and response (Table 1 and Fig. 3).

The analysis of the Table 2 shows that among the total no of respondents only 34.3% were found to have a complete awareness of the risks they were vulnerable to while a majority of about 39.4% had a medium or partial level of awareness and 16.3% were found to a low level of awareness and 1% were found to be unaware of the risks.

Among the partial, low and no awareness groups were mostly the children, disables and women which are already a vulnerable group hence the Risk was increased many folds.

Table 3 shows there is considerable good community involvement in disasters in the study area 70.6% of the sampled population was found to be moderately to highly involved in disaster preparedness and response (Fig. 4).

The analysis of Table 4 revealed that 40% of the sample was trained at least 4 times, 28.6% of the sampled population was trained 3 times, and 11.4% of the sampled population were trained twice. While as rest have received the training only once (Fig. 5).

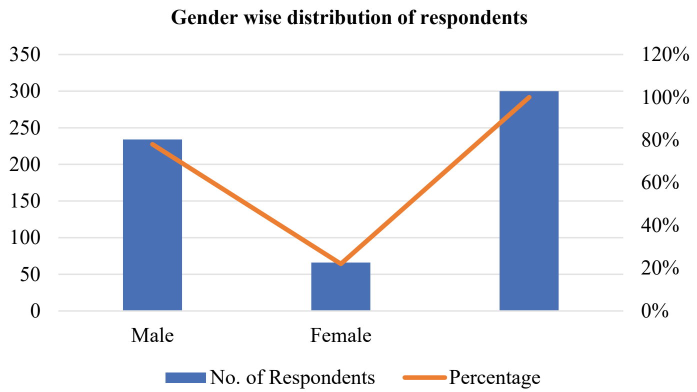


Fig. 3 Gender wise distribution of respondents

Table 1 Gender wise distribution of respondents

S.No	Gender	No. of respondents	Percentage (%)
1	Male	234	78
2	Female	66	22
Total		300	100

Source Field Survey

Table 2 Awareness of risks in the surroundings

S.No	No. of community volunteers	Level of awareness about risks	Percentage (%)
1	103	High	34.3
2	118	Medium	39.4
3	49	Low	16.3
4	30	No	1
Total	300		100

Source Field Survey

Table 3 Community involvement in disaster preparedness

S.No	No. of community volunteers	Involvement in disaster preparedness	Percentage (%)
1	130	High	43
2	92	Medium	30.6
3	34	Low	11.4
Total	300		100

Source Field Survey

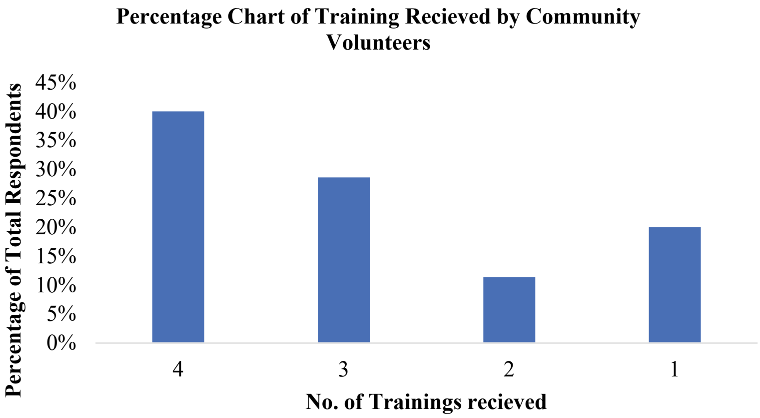


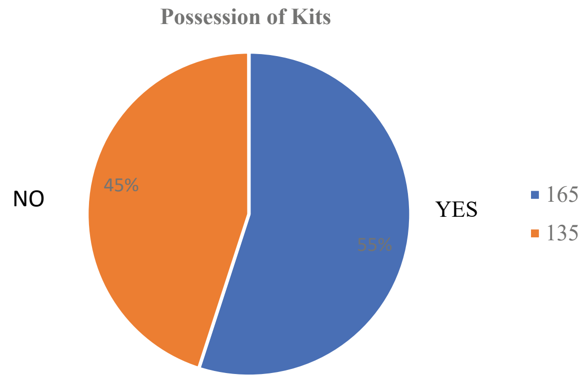
Fig. 4 Percentage chart of training received by community volunteers

Table 4 Training received by community volunteers

S.No	No. of community volunteers	Training received	Percentage (%)
1	120	4	40%
2	86	3	28.6%
3	34	2	11.4%
4	60	1	20%
Total	300		100%

Source Field Survey

Fig. 5 Possession of disaster management Kits by volunteers



The analysis of Table 5 showed that 45% of trained community volunteers lack possession of emergency kits/Disaster Management kits while 55% of the trained and skilled volunteers had the Disaster Management kits with them and those were given to them by the District Administration Srinagar.

Table 5 Possession of disaster management kits by volunteers

S.No	No. of community volunteers	Possession of kits	Percentage (%)
1	165	Yes	55
2	135	No	45
Total	300		100

Source Field Survey

The Result of the study showed that 80% of the sample was trained more than twice and the rest have received the training at least once. The study showed that 45% of trained community volunteers lack the possession of emergency kits which leads to the hindrance in proper response to the disaster events. The study also revealed that after training the community volunteers have developed innovative approaches to reducing the everyday risks they face. However, these community-based approaches are rarely scaled out nor systematically embedded within national and state policies and practices.

6 Conclusion

As a conclusion of the study, it was seen that Training is playing an important role in the capacity building of the community. The community should be made well aware of the risks they are living with, Communities after getting training and awareness become capable of developing their coping mechanisms and strategies to reduce and deal with the impact of the disasters. Effects of the disaster are felt most at a community level and the risk assessment and management are done adequately at the community level only. It is amply clear that nobody can understand the local opportunities and constraints better than the residents themselves and the community is always found to be the first responders to any disasters. Disaster Risk Reduction Activities should be based on the participatory approach wherein local communities should be involved to the maximum level because they are proactive and not just passive targets for the intervention. Building Community Capacities and a chain of trained Community groups/Volunteers can help harness the resilience and resourcefulness of the community. The study also brought our attention to the fact that collaboration, Coordination and participation of the Communities will ensure an effective action during emergencies. It was also concluded that ownership of disaster reduction cannot be separated from local people who are left powerless in case of non-assistance of external agencies. So it becomes imperative that communities should be a part and parcel of Disaster Risk Reduction activities so that their capacities are strengthened and their resilience is enhanced.

7 Suggestions

The purpose of any training and awareness programme is to strengthen the local level capacities for disaster response. To have a capacity building of the communities, the necessary awareness about hazards, risks, vulnerabilities and responses should also be done. Certain thematic areas like the development of plans, etc. should be specifically addressed for community preparedness. Development of Community Contingency plans should be done in consultation with the community members and impart training and awareness to the locals. Identification strengthening of the Task Force groups should be done before planning for any training programme. Community representatives and authorities of local governing bodies should collectively map and identify responsible men, women and youth volunteers who can implement and supervise the activities of the contingency plans.

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