Disaster Risk Reduction
Methods, Approaches and Practices

Gowhar Meraj
Shizuka Hashimoto
Pankaj Kumar *Editors*

Navigating Natural Hazards in Mountainous Topographies

Exploring the Challenges and Opportunities of Living

Springer

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Series Editor

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Disaster risk reduction is a process that leads to the safety of communities and nations. After the 2005 World Conference on Disaster Reduction, held in Kobe, Japan, the Hyogo Framework for Action (HFA) was adopted as a framework for risk reduction. The academic research and higher education in disaster risk reduction has made, and continues to make, a gradual shift from pure basic research to applied, implementation-oriented research. More emphasis is being given to multi-stakeholder collaboration and multi-disciplinary research. Emerging university networks in Asia, Europe, Africa, and the Americas have urged process-oriented research in the disaster risk reduction field. With this in mind, this new series will promote the output of action research on disaster risk reduction, which will be useful for a wide range of stakeholders including academicians, professionals, practitioners, and students and researchers in related fields. The series will focus on emerging needs in the risk reduction field, starting from climate change adaptation, urban ecosystem, coastal risk reduction, education for sustainable development, community-based practices, risk communication, and human security, among other areas. Through academic review, this series will encourage young researchers and practitioners to analyze field practices and link them to theory and policies with logic, data, and evidence. In this way, the series will emphasize evidence-based risk reduction methods, approaches, and practices.

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Preface and Acknowledgements

This book "Navigating Natural Hazards in Mountainous Topographies: Exploring the Challenges and Opportunities of Living" is a product of a collaborative effort between The University of Tokyo and the Institute for Global Environmental Strategies (IGES) in Japan. This work was greatly enriched and broadened during the 6th World Congress on Disaster Management (WCDM) held at Graphic Era University, Dehradun between November 28 and December 2, 2023. The international event served as a valuable forum for discussions that greatly influenced the content and direction of the book.

This book presents a comprehensive examination of natural hazards in mountainous landscapes. It integrates a diverse range of research disciplines to explore the complexities of risk mitigation, adaptive responses, and sustainable livelihoods in the face of environmental challenges. First, this book delves into the geological and hydrological factors that make the Himalayan region susceptible to landslides and employs advanced geophysical methodologies to improve future hazard assessments. Additionally, it examines the susceptibility of these terrains to seismic activities and landslides using cutting-edge technological tools and multi-criteria decision-making frameworks to emphasize the critical role of innovation in disaster preparedness. Then, a significant portion of this book is devoted to investigating the societal dimensions of natural hazards. It delves into how catastrophes jeopardize housing infrastructure and explores the profound socioeconomic consequences on elderly populations living in rural, mountainous regions. As the narrative progresses, it highlights the importance of environmental stewardship and sustainable development. Last section of this book advocates for innovative methods of hazard mitigation and proposes a combination of indigenous wisdom and contemporary scientific methodologies to develop resilience against natural disasters. In light of current trends, the book emphasizes transformative advancements in the disaster management sphere, focusing on the critical roles of early warning systems, community-centered engagement, and the emerging prominence of artificial intelligence in enhancing disaster monitoring and readiness measures. The book also presents detailed analyses of the 'Ghost Villages' phenomenon in Uttarakhand and the health consequences related to high-altitude tourism. These assessments offer insight into the intricate relationship between human societies and their environments, demonstrating how people adapt and interact with the natural landscapes they inhabit. Through this comprehensive examination, readers are provided with a broad understanding of the multifaceted challenges and opportunities that arise from living in mountainous regions prone to natural disasters. This underscores the importance of incorporating diverse knowledge systems and leveraging technological advancements to build sustainable and resilient futures in the face of environmental adversity and climate change induced frequent extreme weather conditions.

We extend our sincere gratitude to the numerous individuals and institutions whose invaluable contributions have been crucial to the completion of this project. We express our deep appreciation to the University of Tokyo and the Institute of Global Environmental Strategies (IGES) for their unwavering support and partnership, which played a pivotal role in the project's success. We also express our gratitude to the Japan Society for the Promotion of Science (JSPS) for their generous financial and logistical support. Particularly, this work was supported by JSPS KAKENHI Grant Number 23KF0024.

We also acknowledge the 6th World Congress on Mountain and Sustainability (WCDM) for providing a fertile ground for intellectual exchange, which also helped crystallize the thematic essence of this book. We extend our thanks to the dedicated authors of each chapter, whose expertise and commitment have been the backbone of this extensive exploration. Finally, we express our profound gratitude to the peer reviewers whose valuable feedback has significantly enhanced the quality of this book.

Acknowledgments are warranted for the invaluable guidance of Prof. Okuro Toshiya and Dr. Huang Wanhui, who have been pivotal in the creation of this book. Our gratitude extends beyond the professional sphere to our families, whose unwavering support and encouragement have been instrumental in our pursuits. Their sacrifices have not gone unnoticed, and their belief in our work has served as a constant source of inspiration. This book is humbly presented to the broader community of readers, stakeholders, and practitioners with the hope that it will impart knowledge and spur actionable insights and innovative solutions for managing natural hazards in mountainous terrains. As we confront the escalating challenges of our time, our collective resolve and shared wisdom pave the way for a resilient and sustainable future.

Tokyo, Japan — Gowhar Meraj
Tokyo, Japan — Shizuka Hashimoto
Hayama, Japan — Pankaj Kumar

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About the Editors

Dr. Gowhar Meraj is a researcher in the domains of hydrology, river basin management, ecosystem services, disaster risk assessment and management, and broader environmental science. Having Ph.D. from Suresh Gyan Vihar University, India, and a Postdoc in Landscape Ecology and Planning from The University of Tokyo, Japan, Dr. Meraj's academic and professional career extends over a decade of significant research and influential contributions. At the core of Dr. Meraj's work lies a dedication to tackling the intricate challenges of climate change, natural disasters, and water resources through state-of-the-art research in GIS, remote sensing, data mining, and artificial intelligence. He has published more than 100 peer-reviewed research publications in reputed international journals. He has also published 07 edited books with some of the notable publishers such as Wiley, CRC-Taylor and Francis and Springer. These accomplishments attest to his profound influence on the scientific community and beyond. Dr. Meraj's career has been marked by his tenure as a JSPS International Researcher at the University of Tokyo, where he does research on transboundary ecosystem services in the Indus Basin. His work emphasizes sustainable strategies and policy-making to enhance environmental resilience in the major river basins of the World. Previously, as a Young Scientist with the Department of Ecology, Environment and Remote Sensing, Government of Jammu and Kashmir, and a Senior Programme Officer at JKDEE&RS, his contributions have been pivotal in climate change impact assessments and disaster risk reduction in the Kashmir Himalayan region. Among his numerous accolades, Dr. Meraj has also been recognized as a Young Scientist by the BRICS Young Scientist Forum, 2022, China. These awards are a testament to his outstanding research and dedication to making a positive impact through research in the world. Beyond his academic and research achievements, Dr. Meraj is a committed educator, mentor, and advocate for environmental sustainability. His involvement in capacity-building initiatives and policy formulation reflects his belief in the power of informed decision-making and community engagement for achieving long-term environmental goals. As a distinguished figure in his field, Dr. Gowhar Meraj continues to inspire younger generation with his unwavering dedication to advancing our understanding of environmental sciences and his contributions toward a more sustainable and resilient world.

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Dr. Shizuka Hashimoto is a distinguished associate professor in the Department of Ecosystem Studies at the School of Agricultural and Life Sciences, the University of Tokyo. Prior to joining the University of Tokyo, Dr. Hashimoto held positions at Kyoto University from 2009 to 2015, the National Institute for Environmental Studies from 2007 to 2009, and the Massachusetts Institute of Technology from 2005 to 2008. Dr. Hashimoto's academic background is in rural planning, and he possesses over a decade of experience in the evaluation of ecosystem services and their application in landscape planning. Throughout his career, Dr. Hashimoto has honed his skills in modeling, land-change and ecosystem service simulation, and scenario analysis. Dr. Hashimoto has published numerous peer-reviewed academic papers and book chapters, and has contributed to the Japan Satoyama Satoumi Assessment as a Coordinating Lead Author. He has also served as an expert group member for Japan Biodiversity Outlook 2 and Japan Biodiversity Outlook 3, and has been appointed by the Ministry of the Environment, Japan as an expert group member to assist in revising the National Biodiversity Strategy and Action Plan. On the international stage, Dr. Hashimoto has contributed to the Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services (IPBES) Global Assessment and the Asia-Pacific Regional Assessment as a Lead Author. Dr. Hashimoto has also served as a Multidisciplinary Expert Panel member of IPBES since 2018, and has held positions as co-chair of the IPBES task force on scenarios and models since 2019, and co-chair of the MEP since 2022.

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Dr. Pankaj Kumar Since March 2024, Dr. Pankaj Kumar has been working as research manager in the field of water resources and climate change adaptation at Institute for Global Environmental Strategies (IGES) at Hayama Headquarter in Kanagawa Prefecture, Japan. In addition, he is also working as head of IPBES-TSU on Scenarios and Models since March 2024. Prior to this, he worked as JSPS/UNU-IAS postdoctoral fellow in United Nations University, Institute for Advanced Study of Sustainability (UNU-IAS), Tokyo; for more than three years. His research work primarily focuses on Socio-hydrology, Water security, Hydrological simulation, Scenario analysis, and Water-health-food-energy nexus. To address his research objectives, he uses integrated approach involving both qualitative and quantitative analysis. One of the important works that he is recently engaged in is 'Water quality assessments and scenario modeling for clean water environment in both South and South-East Asian regions' a transdisciplinary work; which aims to enhance community resilience to address growing water demands under climate change and rapid urbanization, with ultimate intention to give a solution for sustainable water resource management at policy level. Along with that, he is also engaged in teaching focuses on assessing the impact of global climate change on water resources and weighing on adaptation and mitigation options to offer scientific solutions. Right after completing his doctoral research, he worked as assistant professor in the Department of Environmental Science and Technology at Institute of Science and Technology for Advance Studies and Research, Gujarat, India. He completed his doctoral degree in July, 2012 from University of Tsukuba, Japan.

In parallel, he has work experience as Chapter Scientist for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). He was associated with the IPCC's Working Group-II report that focuses on "Impacts, Adaptation, and Vulnerability" which was released in December 2014. Also, now he is working as *lead author* for Chapter-3 *Future interactions across the nexus* for the nexus assessment of the interlinkages among biodiversity, water, food and health in the context of climate change under *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)* secretariat. Moreover, he is also working as lead author for Chapter-19 *Disaggregated solutions pathway scenarios* for the Global Environment Outlook 7 (GEO 7) assessment report from United Nations Environment Programme (UNEP).

His research understanding got places in authored book (n = 1), edited book (n = 1), journal special issue (n = 1), peer-reviewed journal articles (n = 183), book chapter (n = 17), UN-books/monographs (n = 3), global assessment reports (n = 3), and conference proceedings (n = 41).

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Chapter 1
Foundations and Frontiers of Natural Hazard Management in Mountainous Regions

Gowhar Meraj, Shizuka Hashimoto, and Pankaj Kumar

Abstract Mountainous regions around the world are at the forefront of climate change and natural disasters. The unique geomorphological features, diverse ecosystems, and climatic extremes of these areas create breathtaking landscapes; however, these same characteristics also make them hotspots for environmental hazards. The frequency and severity of landslides, earthquakes, floods, and glacial lake outburst floods (GLOFs) pose ongoing threats to both the communities living in these regions and the surrounding natural environments. These hazards are intensified by unsustainable development practices, and environmental degradation, highlighting the critical vulnerabilities faced by mountainous areas. The challenges of managing natural disasters in such terrains are further complicated by global warming and climate change, which exacerbates the risk and impact of hydro-meteorological hazards through the melting of glaciers and alteration in precipitation patterns. This scenario hightlights the urgent need to understand the dynamic interplay between human activities, climate change, and natural disaster risk, and the necessity for innovative and adaptive management strategies. As societies grapple with these challenges, the importance of integrating traditional knowledge with the latest scientific research and technological advancements becomes increasingly evident. This approach aims to enhance disaster risk reduction efforts while also ensuring the sustainability of interventions, taking into account the socio-economic and cultural dimensions of the affected communities. In this context, addressing the vulnerabilities and increasing the resilience of mountainous regions to natural hazards requires a comprehensive and coordinated effort. This is the focus of this book, providing case studies and understanding from different regions of the world so as to demonstrate collaboration among local communities, scientists, and policymakers, in order to foster the development of effective strategies that mitigate the impact of natural disasters.

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The book comprises two primary sections, the first of which focuses on understanding the factors responsible for hazards, and the second on management options for approaches to adaptation, mitigation, and management. Each section is further divided into several chapters that explore various aspects of disaster management in mountainous regions, including the impacts of climate change, the role of traditional knowledge, the application of remote sensing and GIS technologies, and the development of early warning systems and community-based preparedness programs. This book demonstrates the need for inclusive, adaptive, and sustainable management strategies that consider the unique needs and perspectives of mountain communities. By adopting these strategies, we can create resilient mountain communities that are better prepared to face the challenges posed by changing climate and natural hazards.

Keywords Climate change · Natural hazards · Mountainous regions · Disaster risk reduction · Sustainable development

1.1 Introduction

Mountainous regions across the world are inherently more exposed to natural disasters due to their geomorphological features (Meraj et al., 2015, 2018), climatic conditions (Dolgorsuren et al., 2024), and delicate ecosystems (Meraj, 2021, Meraj et al., 2022). The complex topography of these regions, combined with climatic extremes, increases the frequency and severity of hazards such as landslides, earthquakes, floods, and glacial lake outburst floods (Ahmed et al., 2022), posing a constant threat to both the environment and the communities living in these areas. Studies by Hewitt (2016a, b) and Bajracharya et al. (2015) emphasize the dynamic nature of these hazards, attributing their intensification to both natural processes and human activities, including climate change and unsustainable development practices. According to Bankoff et al. (2004), vulnerability is not only a consequence of environmental threats but also a result of how societies organize themselves in relation to their environment, manage natural resources, and mitigate risk. This perspective is crucial in mountainous areas, where the compounded effects of socio-economic factors and environmental degradation exacerbate the impact of natural disasters.

The susceptibility of mountainous regions to natural disasters is further compounded by the consequences of global climate change (IPCC, 2014; Nie et al., 2021). Studies have documented the increasing variability of precipitation patterns and the rising temperatures as significant contributors to the melting of glaciers and snowpacks, leading to increased instances of GLOFs and avalanches (Dimri et al., 2021). Additionally, climate change acts as a multiplier of disaster risk, exacerbating the frequency and impact of hydro-meteorological hazards (Kraaijenbrink et al., 2017; Shugar et al., 2020). The cascading effects of these hazards not only result in immediate loss of life and property but also have long-term consequences on the socio-economic development of mountainous regions. Studies by Ives et al.

(2010) and McDowell et al. (2014) have emphasized the intricate link between environmental degradation and the livelihoods of mountain communities, highlighting the critical role of sustainable development and adaptive management in reducing vulnerability to natural hazards. Further, AghaKouchak et al. (2020) highlight the significant threats posed by climate extremes, which are increasing in frequency and intensity due to global warming, to human health, economic stability, and both natural and built environments. Terzi et al. (2019) also emphasize the particular vulnerability of mountain regions to climate impacts, including alterations in the water cycle and losses in biodiversity, which directly affect local economies and human safety. This comparative analysis showcases the potential of system dynamic and hybrid models in effectively addressing climate change effects and enhancing adaptation strategies in mountain environments.

Effective disaster risk management in mountainous regions necessitates a comprehensive and coordinated approach that successfully merges local knowledge with the most recent scientific research and technological advancements. The introduction and implementation of remote sensing and Geographic Information Systems (GIS) technologies have significantly transformed the field of hazard assessment and monitoring, providing unmatched precision in predicting and issuing early warnings for natural disasters (Bhattarai et al., 2024; Tullos et al., 2016). Simultaneously, the appreciation of indigenous knowledge and practices in the development of disaster risk reduction (DRR) strategies has increasingly been recognized for its profound capacity to enhance community resilience and ensure long-term viability (Amirzadeh et al., 2021). The integration of these diverse knowledge systems, when supported by active collaboration among local communities, scientists, and policymakers, paves the way for the creation of more comprehensive and effective strategies to manage natural hazards in mountainous regions.

Recent advancements in technology and research emphasize the importance of combining state-of-the-art scientific methodologies with traditional knowledge to enhance disaster risk reduction (DRR) efforts. For example, the utilization of machine learning algorithms and big data analytics in the processing and interpretation of extensive datasets obtained from remote sensing technologies has opened new avenues for understanding and mitigating disaster risks in complex mountainous environments (Taylor et al., 2021). Furthermore, the burgeoning field of climate informatics has introduced innovative tools for modeling climate change impacts, providing valuable insights into future hazard scenarios and enabling more proactive DRR planning (Balogun et al., 2020). Sustainable land-use planning and environmental conservation emerge as crucial components of effective disaster risk management, particularly in light of the exacerbating impacts of climate change (Nguyen et al., 2023). Strategies aimed at preserving natural buffers and enhancing ecosystem services contribute to reduce hazard exposure as well as play a vital role in maintaining biodiversity and securing water resources, which are indispensable for mountain communities (Duc et al., 2024; Mishra et al., 2021). Moreover, climate change adaptation measures that incorporate both structural and non-structural solutions, ranging from the reinforcement of infrastructure to the implementation of early warning systems and community-based preparedness programs, are essential in building resilience against the increasing threat of natural hazards (Chisty et al., 2022; Speizer, 2022; Willison et al., 2022).

1.2 The Structure and Concept of This Book

"Navigating Natural Hazards in Mountainous Topographies—Exploring the Challenges and Opportunities of Living" is a highly significant publication that greatly contributes to the ongoing discourse on climate change and its consequences for disaster management. This book brings together advanced technological approaches, traditional knowledge systems, and scientific modeling to establish a comprehensive framework for communities worldwide facing natural disasters in mountainous regions. These areas are particularly susceptible to natural hazards, including landslides, floods, and earthquakes, which are exacerbated by the consequences of climate change and pose a severe threat to the well-being, livelihoods, and cultural heritage of communities residing in these regions. Studies have highlighted the compounded vulnerabilities experienced by these communities and the ecosystems they depend on, stressing the need for adaptive, inclusive, and sustainable management strategies (Maskrey et al., 2023; Versey, 2021). This book delves into recent scholarly research to examine the intricacies of disaster management in mountainous regions.

This book is based on the fundamental understanding that mountainous regions serve as both repositories of important cultural and ecological resources and hotspots for natural disasters. Tullos et al. (2016) conducted a thorough examination of flood risk management dynamics in high mountain regions. Their research highlighted the intricate interplay between topography, hydrogeology, governance, and climate change, revealing the complex challenges faced by these areas. By recommending practices such as comprehensive hazard assessments, disaster response planning, and engaging local communities, Tullos et al. provided a practical and insightful guide for minimizing flood risk. These recommendations are consistent with Hewitt's (2016a, b) work, which investigated the environmental and social aspects of disasters within the mountain cryosphere. Hewitt's study explores diverse cryospheric hazards and their compounded dangers in steep terrains, shedding light on the unique threats posed by phenomena such as glacial lake outburst floods and snow avalanches. This research not only expands the scope of disaster risk considerations in mountainous environments but also contextualizes these risks within the larger framework of climate change and human ecological relationships.

Drawing on the topic of vulnerability, Sekhri et al. (2020) conducted a study to evaluate the effects of multi-hazard risks in the Indian Himalayan Region using the IPCC framework, which comprises exposure, sensitivity, adaptive capacity, and coping mechanisms. Their research emphasizes the importance of acknowledging spatial specificities in risk-mitigation strategies and proposes a mountain-specific risk management framework that prioritizes habitation resilience, natural capital enhancement, and technological interventions, among other strategies. This approach underscores the necessity of customizing disaster management efforts based on the unique characteristics of mountainous communities. Alcántara-Ayala et al. (2022) recommended the establishment of a global policy agenda that recognizes the interconnected nature of risk and the vital role of mountain ecosystems in ensuring global sustainability. Their research highlights the need for combined knowledge and action to safeguard vulnerable populations and promote sustainable growth and stability in mountainous regions, which is consistent with international frameworks aimed at achieving long-lasting peace. Hsu et al. (2015) investigated the experiences of Indigenous Rukai communities in Taiwan and shed light on the difficulties inherent in post-disaster rebuilding efforts. This study emphasizes the necessity of disaster recovery strategies that are culturally sensitive and inclusive to avoid perpetuating existing disparities. The following provides a comprehensive guide to this book: This book serves as a robust foundation for disaster management in mountainous regions and functions as an essential resource for policymakers, practitioners, researchers, and communities. By integrating diverse perspectives and equipping readers with the knowledge and tools necessary for fostering resilience and ensuring sustainable living in the face of natural hazards, this book constitutes a valuable asset for anyone working in or affected by these regions.

This volume sets out to combine contemporary geospatial technologies, traditional knowledge systems, and advanced modeling techniques to lay the groundwork for sustainable disaster mitigation and management. The book is structured into two primary sections: Part I: Understanding the Hazards and Part II: Approaches to Mitigation and Management. This organization allows for a thorough examination of both the theoretical principles and practical applications of contemporary disaster management practices.

Part I of this book, titled "Understanding the Hazards," is composed of two sections designed to offer a thorough comprehension of the geospatial and geological factors that contribute to natural disasters, followed by an in-depth analysis of recent case studies. The first section presents a solid foundation of knowledge, while the second offers practical insights into the theoretical underpinnings and implications of natural hazards in various geographical contexts. This unique approach allows readers to gain a comprehensive understanding of both the principles and the practical applications of natural hazards.

The opening section, "Geospatial and Geological Insights," examines the vital role that geological and hydrological factors play in determining a region's vulnerability to natural disasters. This underscores the importance of employing geospatial technologies and methodologies to gain a nuanced understanding of these elements and their interplay. Chapter 2 explores the significant yet frequently overlooked part that groundwater plays in triggering landslides. This chapter delves into the hydrogeological dynamics present in the Himalayan region, emphasizing the need to integrate hydrological insights into landslide risk assessments. Chapter 3 expands on this topic by illustrating the application of geospatial modeling techniques for evaluating seismic risks. Through a comprehensive case study, this chapter demonstrates how the combination of entropy methods with the Analytical Hierarchy Process (AHP) offers a solid framework for seismic risk evaluation, taking into account the unique geotectonic features of the Himalayas. Chapter 4 further highlights the potential of geospatial technology. By focusing on the Sikkim and Darjeeling regions, this chapter shows how AHP and geospatial techniques can be combined to model landslide susceptibility, serving as a crucial tool for hazard mitigation and risk management.

Transitioning from theoretical frameworks and modeling techniques, the section titled "Case Studies on Recent Disasters and Their Impact" offers a practical perspective on the real-world implications of natural hazards. This section draws from recent events to highlight the challenges and lessons learned from disaster management and recovery efforts. Chapter 5 examines the devastating impact of the Afghanistan Earthquake on the housing sector. This chapter underscores the critical insights gained from post-disaster housing recovery efforts and provides valuable lessons for future disaster preparedness and resilience building. Chapter 6 explores the unique challenges faced in the aftermath of heavy rainfall events in Japan. Focusing on the geographical and infrastructural vulnerabilities of mountainous areas, this chapter discusses reconstruction efforts and strategies implemented to overcome these challenges. Chapter 7 provides a comprehensive overview of various mountain hazards that have impacted Japan for nearly a decade. Through this historical lens, the chapter delves into the patterns of damage and evolving approaches to disaster management and mitigation. Chapter 8 concludes the section by focusing on the geological aspects of landslides in the context of Japanese mountain hazards. This chapter highlights the importance of geological information in understanding landslide dynamics, thereby informing more effective prevention and mitigation strategies. Together, the chapters in Part I lay a solid foundation for understanding the multifaceted nature of natural hazards, bridging theoretical knowledge with practical insights to illuminate the path toward more resilient and adaptive disaster management practices.

Part II of the book focuses on "Strategies for Mitigation and Management," which delves into practical approaches and methodologies for reducing the consequences of geological hazards and effectively managing potential disasters. This section is divided into two main areas of thematic concern: "Leveraging Technology and Knowledge," and "Environmental and Social Considerations," each comprising chapters that present innovative and effective strategies for minimizing disaster risks and managing potential disasters.

The first section of Part II, titled "Leveraging Technology and Knowledge," emphasizes the pivotal role of technological advancements and the integration of traditional knowledge in enhancing disaster mitigation and management efforts. In Chap. 9, an advanced method for mapping sediment runoff after mountain disasters is introduced. This chapter employs remote sensing techniques to demonstrate how wide-area extraction methodologies can significantly improve our understanding and response to sediment-related disasters in mountainous areas. Chapter 10 underlines the inestimable value of local and indigenous knowledge systems in geohazard mitigation. Through a case study in Nigeria, this chapter illustrates how community-based knowledge can complement scientific approaches and provide holistic and culturally sensitive disaster management solutions. Chapter 11 offers a comprehensive examination of how geology and GIS technologies can be utilized to prevent future floods.

By presenting a case study of Pakistan, this chapter highlights the potential of integrating geological insights and GIS applications in crafting effective flood management strategies. Chapter 12 discusses the application of the relative effects method for assessing landslide susceptibility. This methodological approach, combined with case studies from the NW Himalayan region, demonstrates that precise susceptibility mapping can guide effective landslide risk management and mitigation efforts.

This second section of Part II emphasizes the importance of incorporating environmental sustainability and social factors into disaster management practices. Chapter 13 explores the relationship between community engagement and artificial intelligence in enhancing disaster preparedness and responses, advocating for a participatory approach to disaster management in which AI tools are utilized to bolster community-driven initiatives. Chapter 14 examines the phenomenon of "Ghost Villages" as an outcome of rural migration in Uttarakhand, India, using remote sensing technologies, and emphasizes the need to address these issues in disaster risk reduction strategies. Chapter 15 examines the health risks associated with high-altitude adventure tourism and stresses the importance of adopting sustainable tourism practices that minimize ecological and sociocultural footprints while ensuring appropriate health and medical support for tourists. Chapter 16 discusses the application of the J-ADRES database in promoting ecosystem-based disaster risk reduction (Eco-DRR) strategies, focusing on societies with declining populations, and highlights how land-use planning and management, informed by the Eco-DRR principles, can contribute to sustainable and resilient community development. Part II provides a comprehensive overview of the diverse approaches to disaster mitigation and management, emphasizing the importance of integrating technology, knowledge, environmental sustainability, and social considerations to develop effective and resilient disaster response strategies.

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Part I
Understanding the Hazards Geospatial and Geological Insights

Chapter 2
Groundwater and Its Impact on Landslides Along Himalayan Regions: A Review

Ajit Kumar Behera, Rudra Mohan Pradhan, Amulya Ratna Roul, and Pankaj Kumar

Abstract Landslides are complex, dynamic processes influenced by erosion, weathering, tectonics, and gravity, triggered by various geotechnical, biological, mineralogical, and hydrological factors. Detailed studies on landslide mechanisms typically focus on specific high-risk cases. The stability of slopes and the physical and mechanical properties of sediments can be affected by their grain size, chemical composition, mineralogy, and the chemistry of circulating water, underscoring the need for a multidisciplinary approach to studying these processes. Additional hydrogeochemical processes, such as carbonate and iron compound precipitation, and the exchange of cations with different valences, can further modify the shear strength of shear zones. Various geophysical methods are actively employed for landslide investigations in Uttarakhand, with the EVRI geophysical method potentially being a novel technique for future use. The most commonly utilized technique is GIS, which has been employed to evaluate landslides in this area. Moreover, monitoring spring discharge and groundwater levels can aid in predicting landslides in these regions.

Keywords Groundwater · Springs · Landslides · GIS · Geophysical methods · Himalaya

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2.1 Introduction

Landslides stand as one of the most prevalent natural hazards worldwide (Kjekstad and Highland, 2009). Based on the Center for Research on the Epidemiology of Disasters (CRED), 17% of fatalities resulting from natural hazards can be attributed to landslides. An estimated land area of 3.7 million km^2 and approximately 5% of the global population, totaling around 300 million individuals, face exposure to landslides. Among these, 66 million people reside within high-risk zones (Dilley, 2005). Infiltration of rainfall into slopes often leads to an elevation in groundwater levels plays a pivotal role in initiating landslides. Numerous studies have delved into examining the correlation between groundwater and landslide dynamics (Iverson, 2005; Matsuura et al., 2008; McKenna et al., 2012; Hong & Wan, 2011; Wang et al., 2020).

The elevation of groundwater levels can escalate pore water pressure and diminish the shear strength within slip zones. Typically, elevated groundwater levels and sudden changes are considered harmful to the stability of slopes. When groundwater exceeds a certain limit, it has the potential to trigger landslides that move swiftly (Iverson & Major, 1987). In specific scenarios, the behavior of bedrock concerning its geology, level of fracturing, weathering, and saturation determines whether it functions as a reservoir or a contributor to groundwater within the overlaying landslide. The hydrogeological mechanisms that trigger landslides are highly complex. Each landslide exhibits a distinct pattern of groundwater flow. Pinpointing the origin of groundwater and its pathways within landslides is frequently challenging. In the past thirty years, the comprehension of hydrogeological processes in hillslopes has advanced significantly, primarily owing to interdisciplinary monitoring methods. These encompass a range of techniques such as geophysical and geotechnical approaches (e.g., Agliardi et al., 2020; Crawford & Bryson, 2018; Strauhal et al., 2017), hydrochemical and isotopic investigations (e.g., Cervi & Tazioli, 2021; de Montety et al., 2007; Deiana et al., 2018; Guglielmi et al., 2000; Krzeminska et al., 2012; Ronchetti et al., 2009), occasionally combined with mineralogical analysis (e.g., Bolla et al., 2020; Zhao et al., 2011). Vegetation impacts slope stability indirectly through interception, altering the total volume and timing of rainfall reaching the soil surface (McGuire et al., 2016). Additionally, vegetation can enhance the effective permeability of underlying bedrock through root penetration. Changes in slope stability due to vegetation can immediately impact the risk of landslides. Over longer periods, these changes can also affect soil thickness in steep landscapes and erosion rates by influencing how sediment is transported through debris flows (Gabet & Dunne, 2002). The latest study by Rengers et al. (2016) revealed that locations where landslides initiate align with areas of low vegetation density, irrespective of the slope aspect. However, vegetation can affect slope stability through mechanisms like root-driven mechanical weathering, intercepting rainfall, or providing apparent soil cohesion, the specific physical causes behind the perceived pattern linking debris flow initiation to slope aspect remain unclear (McGuire et al., 2016). Hence, for a precise assessment of how future changes in vegetation type will affect landslide hazards on steep hillslopes, it is crucial to improve the quantification of vegetation's role in soothing hillslopes during intense rainfall events.

The susceptibility of the Indian Himalayan region to landslides stems from a combination of factors including its intricate geological composition, rugged terrain, steep slopes influenced by seismic activities, and heavy rainfall (Das et al., 2023) (Fig. 2.1). Cruden and Varnes (1996) delineated distinct categories encompassing geological, morphological, physical, and human factors. In the mountainous landscape of the Indian Himalayas, extensive heavy rainfall during the monsoon season is the primary condition leading to the formation of profound landslides due to increased water table levels (Panda et al., 2023). Under significant rainfall intensities, a perched water table has the potential to emerge above the primary water table, potentially diminishing stability to the extent that landslides could be initiated under specific conditions (Take et al., 2015). Limited research has focused on identifying, describing, quantifying, and dating extensive landslides. Comprehensive investigations are essential both within specific regions and across different areas characterized by active erosional and tectonic activities, as well as steep terrain, as these conditions create an environment conducive to the occurrence of significant landslides. The paper offers a brief overview suggesting that landslides triggered in situations of increased groundwater may demonstrate higher movement compared to those in drier conditions. This notion is derived from observations of recent incidents in the Himalayan regions.

2.2 Study Area

Uttarakhand comprises diverse geological features, encompassing a range of rock types dating back from the Achaean to Quaternary periods (Fig. 2.1). Based on this temporal and spatial geological diversity, the state can be divided into two primary physiographic and tectonic units. First, the Gangetic Alluvial Plain is located in the southernmost region, this area is part of the Indo-Gangetic Foreland Basin and comprises Quaternary fluvial sediments which is known as Ganga Alluvium. Studies have uncovered a substantial accumulation of alluvium atop the Siwalik succession from the Neogene to the early Pleistocene Period (GSI, 2018a, b). The alluvial deposit thickness increases towards the north, reaching its peak near the Foot Hill Fault (FHF), demarcating the northern extent of the Ganga Foredeep Basin. These sediments overlay the Precambrian cratonic rocks of the Peninsular Indian Shield. Secondly, the Himalayan Mountain Belt (Extra Peninsular Belt) is a part of the global mobile belt formed during the Mesozoic to Cenozoic era through the convergence of the passive Eurasian Plate and active Indian Plate through continent–continent collision. While a small portion of the Himalayas comprises late Proterozoic to early Cenozoic crustal sequences, the primary mountain range is predominantly made up of Proterozoic rocks originating from the Indian Shield. These crystalline hard rocks have undergone different orogenic episodes from the Mesozoic to the Cenozoic era,

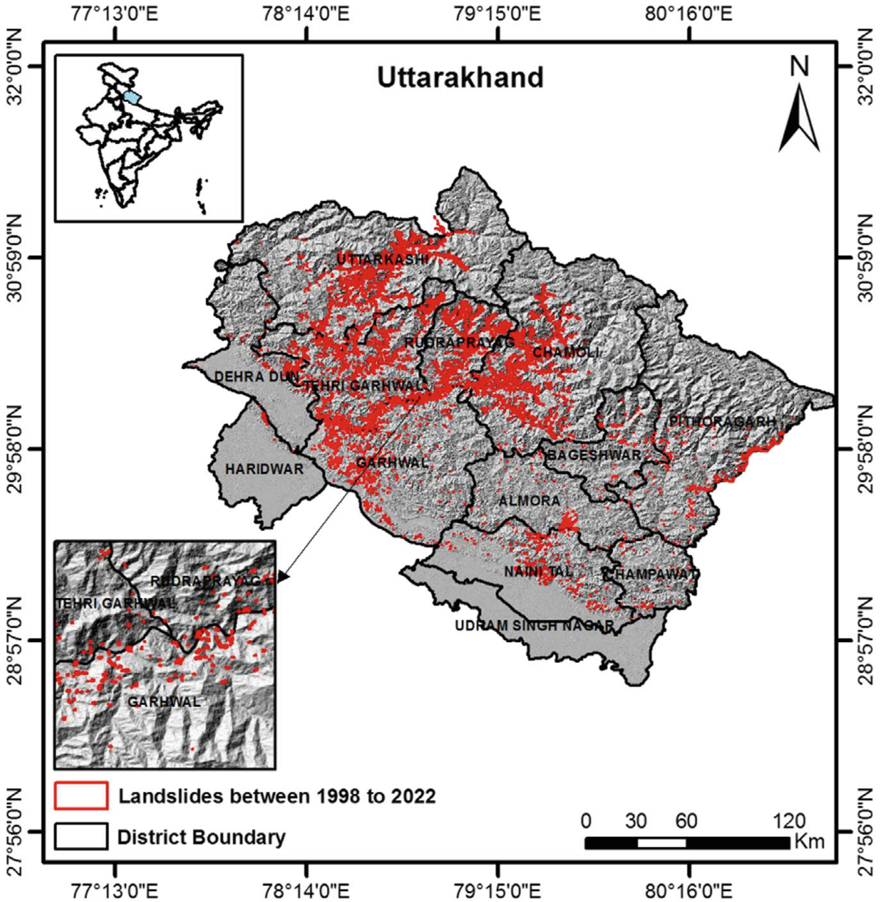

Fig. 2.1 Landslide map of Uttarakhand between 1998–2022 (Jain et al., 2023)

displaying metamorphism and multi-phases of deformation. The Extra Peninsular section houses a diverse array of igneous, metamorphic, and sedimentary rocks.

2.3 Methods

2.3.1 Geographic Information System (GIS) techniques

Over the past decade, from 2013 to 2023, researchers have utilized GIS methods extensively to evaluate landslide risks within the Himalayan regions. The surge in publications correlates with the frequent occurrences of landslides in this relatively

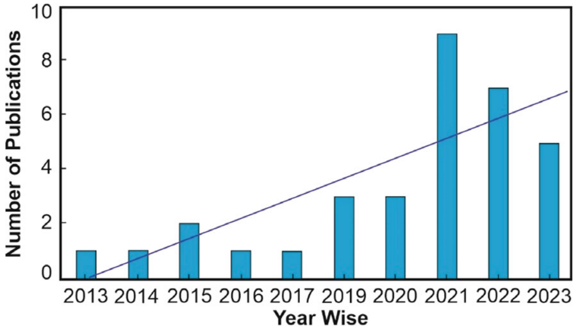

Fig. 2.2 Geographic Information System (GIS) techniques used in landslide research publications in the last decade (year-wise)

unstable area (Fig. 2.2). Primarily, authors have employed the Analytical Hierarchy Process (AHP) technique to delineate the Landslide Hazard Zones (LHZ).

2.3.2 Geophysical Techniques

For water-induced landslides, several geophysical methods viz. electrical resistivity tomography (ERT) (Falae et al., 2021a, b), ground-penetrating radar (GPR) (Borecka et al., 2015; Jongmans & Garambois, 2007), and seismic (Pareek et al., 2010) methods can be employed. GPR uses high-frequency radar pulses to image the subsurface. It can help identify changes in material properties, such as water content, which is crucial for understanding landslide processes. GPR can be effective in detecting elevated moisture levels in the soil, indicating potential areas prone to landslides. Electrical Resistivity Tomography (ERT) measures the electrical resistivity of subsurface materials. Wet soil typically has lower resistivity than dry soil. By mapping variations in resistivity, ERT can provide insights into changes in water content, helping identify areas susceptible to landslides. On the other hand, Seismic surveys can be used to study the subsurface structure and identify potential sliding surfaces. Changes in seismic velocities can indicate variations in material properties, including the presence of water. Seismic refraction and reflection surveys are examples of seismic methods applicable to landslide studies.

2.4 Results and Discussion

2.4.1 Case Study-1: Kuwari Landslide

Kuwari village sits in the lesser Himalayan tectonic block and is squeezed among the Main Boundary Thrust (MBT) to the south and the Main Central Thrust (MCT) to the north. Moreover, this village is located on overburden material (Colluvium) with

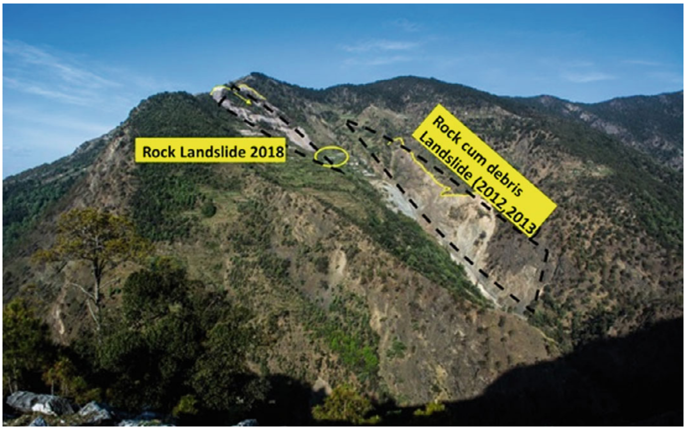

Fig. 2.3 Kuwari landslide (after GSI, 2018a)

few outcrops, where phyllite/slate is well-exposed along the Nala flowing northeast, close to the village's north. The hill slopes of Kuwari village are made up of thinly foliated, sheared, moderately weathered phyllite/slates. The percolation of meteoric water through the subsidence and cracks in the colluvium material has resulted in the removal of finer material, leading to piping action. Further, rainfall can increase the water content in the soil, leading to an increase in pore water pressure. This increased pressure can reduce the strength of the soil, making it more prone to landslides or slope failures. The additional weight of the water can also add to the destabilization of slopes, especially in areas with steep terrain or loose soil. This phenomenon manifests on the ground as indicated in Fig. 2.3.

2.4.2 Case Study-2: Hathi Parvat Landslide, Chamoli District

This region is primarily barren, with sparse vegetation in some areas. Gneissic rock is exposed along the road and in the upper reaches, often interspersed with thin mica schist bands. The material involved in the landslide consists of angular rock blocks and fragments. The rock mass has been loosened and its shearing strength reduced due to rainfall, uncontrolled blasting, and unplanned road widening activities without immediate and proper slope protection measures (Fig. 2.4). This weakening of the rock mass intensified the failure during the initial heavy rainfall.