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Manish Pandey · Gregory Giuliani ·
R. K. Sharma · Prashant K. Srivastava *Editors*

Geo-information for Disaster Monitoring and Management

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Editors

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Dedicated to disaster-affected populations

—Prem C. Pandey, Rajesh Kumar, Manish Pandey, Gregory Giuliani, R. K. Sharma, Prashant K. Srivastava

Foreword by Prof. Kamlesh Lulla

Global communities are increasingly dealing with both natural and man-made disasters on a vast scale. Recent disasters have impacted populations all across the globe for example: Haiti earthquake -227000 deaths, Myanmar cyclone_141000 deaths, Venezuela floods-35000 deaths according to data compiled by various national and international agencies. The European region and the United States have experienced massive floods in recent years. The economic impact of disasters caused by severe storms and floods alone reached over USD 150 billion by some estimates. The frequency, intensity, scale and scope of the disasters has been a great cause for concern in the scientific communities. Rapid advances in remote sensing, image processing, geospatial, and related geo-information technologies combined with the emerging technologies of deep machine learning and artificial intelligence provide researchers opportunities to monitor, manage and model the disasters with better predictability and accuracy. These technologies would aid in better decision-making for disaster mitigation and aid in rapid recovery. This book is an excellent resource for not only scientists and students but also for decision makers and agencies whose primary focus is to develop an in-depth understanding of disasters, and monitor, manage and assist in recovery after the disaster.

The highly experienced editors and authors of this book have skillfully provided an extensive discussion on geo-information technologies on the subject. There is an outstanding synthesis of several case studies to provide insights into the science related to disaster management, to understand their potential to cause damage the habitats and infrastructure and impact to human populations. In addition, discussion on monitoring tools and techniques are also highlighted.

This well thought out resource book contains twenty-two chapters that cover disasters categories and monitoring processes using geo-information techniques to illustrate the recent and relevant advancements. In my view, this comprehensive coverage of geo-information technologies for disaster monitoring and management is a giant leap and a significant contribution to this growing body of knowledge. The editors are also to be commended for inviting subject matter experts from each of the broad disaster categories to author the chapters in their areas of research. Their expertise is evident from the contents of the book.

The most notable aspect of this excellent volume is that it introduces most updated information relative to the disaster categories, including case studies and advanced techniques useful at different scales. The chapters offer very extensive references and reading materials that will aid users in conducting their on disaster related to research and analysis.

There is a growing interest in advancing the applications of geo-information technologies to disaster related research, recovery and decision making. This book promises to be an ideal resource for anyone who is involved in disaster related education and research: from undergraduate and postgraduate students and PhD scholars to university faculty and independent researchers.

I congratulate Dr Prem Pandey for assembling this outstanding group of contributors for this book. I also congratulate each and every author for their contributions to the publication which will serve an invaluable resource for years to come. Future of our planet and our communities depends upon sound understanding of disasters and using science for their mitigation and recovery of habitats.

Prof. Kamlesh Lulla, Ph.D.
Fmr. Chief Scientist for Earth
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Houston, TX, United States

Dr. Kamlesh Lulla is an award-winning, internationally acclaimed NASA chief scientist and an expert in space and geospatial technology who is senior scientist and leader at NASA for the past 36 where he has served as the Chief Scientist for Earth Observation for Space Shuttle and International Space Station programs, directed the training of NASA Astronauts in Earth Observation Sciences and physical science payloads. Dr. Lulla's scientific research involved optical and radar remote sensing and advanced sensor development. In addition, Dr. Lulla developed digital imaging sensors as payloads for the space shuttle program. In his leadership roles at NASA, Dr. Lulla also served as Chief for Flight Science branch for five years and Chief for Earth Science branch for five years. He also served as the Chief Scientist for ten years.

Dr. Lulla holds two Ph.D. degrees with expertise in Environmental science and Geoscience remote sensing. He served in academia as a tenured university professor of Remote Sensing and Earth sciences. He has co-authored or edited eight books and authored a large number of research and technical papers in prestigious journals. He is also the Editor of a major international journal in Earth and space science and Remote Sensing, Geocarto International.

Dr. Lulla has received numerous awards from NASA, the U.S. Government and professional societies such as the American Institute of Aeronautics and Astronautics (AIAA), American Society of Photogrammetric Engineering and Remote Sensing (ASPRS) and Association of American Geographers. Dr. Lulla received three of

the highest NASA medals- the NASA Exceptional Achievement Medal for his scientific research and NASA sponsored Astronaut Ellison Onizuka Award (medal) for his scientific and technical excellence and NASA Exceptional Service Medal. In 2015, India's President honored Dr. Lulla with the Medal and Award for Overseas Indian Immigrants (Pravasi Bhartiya Samman) for his lifetime achievements in space science and technology.

Foreword by Prof. (Dr.) Shailesh Nayak

Amidst a shifting climate landscape, natural and anthropogenic factors intensify the occurrence and impact of disasters. Changing weather patterns lead to heightened frequencies of events like droughts, floods, and cyclones, exacerbating vulnerabilities within communities. To address these challenges, geoinformatics plays a pivotal role in climate change adaptation and disaster mitigation. Experts can model risks, forecast potential impacts, and implement effective response strategies by leveraging Geographic Information Systems (GIS), remote sensing, and spatial analysis. For instance, GIS mapping helps identify hazardous zones and track their evolution in real-time, while satellite data provides critical insights into the extent and intensity of natural calamities. Embracing renewable energies, sustainable practices, and international cooperation remains essential to reducing the scale and frequency of natural disasters.

Chapters in this edited volume deal with geophysical, hydrological, meteorological, climatological, biological and man-made disasters that caused enormous damage to human lives, livestock, crops, livelihoods, agricultural lands, movable and immovable properties, culture and environment despite substantial monetary investment in managing the adverse impact of disaster worldwide. Since we live in the digital mapping era, earth scientists and policymakers are emphasizing mapping the extent and seasonality of a particular disaster or a group of disasters using geospatial technology. Further, mapping the extent of a disaster and different types of resources therein are the main steps towards managing the future disaster risk. In this context, the Sendai framework (2015–30) also aims to reduce the size of the disaster to minimize the disaster risk and, ultimately, tangible and intangible losses.

The present volume titled 'Geo-information for Disaster Monitoring and Management' is edited by scholars who are working in the field of applications of remote sensing, GIS and sophisticated surveying instruments in disaster monitoring and its management. This book's editors and contributors aim to offer comprehensive discussions on geoinformation techniques for disaster monitoring. They include various case studies to delve deeper into disaster impacts, assessing damage potential, effective and practical ways to track these events. Notably, the editorial team has invited experts across diverse disaster themes to contribute, resulting in a compilation

covering multiple disasters with case studies and advanced methodologies at varying scales.

This volume serves as a valuable resource and reference for understanding disasters, their typology, and technological approaches to monitoring them. It is anticipated to benefit researchers, Earth scientists, urban planners, and policymakers by facilitating the application of geoinformation in disaster management and reducing risks associated with such events.

In recognition of their efforts, I applaud the team for taking up this significant endeavour, which promises to impact numerous research and professional communities in the coming years.

Prof. (Dr.) Shailesh Nayak
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Dr. Shailesh Nayak is currently the Director of the National Institute of Advanced Studies, Bengaluru, Chancellor of the TERI School of Advanced Studies, Delhi, Editor-in Chief, Journal of the Indian Society of Remote Sensing and Life Trustee, India International Centre, New Delhi. Dr. Nayak obtained Ph. D. degree in Geology from the M.S University of Baroda in 1980. He was the Secretary to the Government of India, for the Ministry of Earth Sciences (MoES), between August 2008–2015. He provided leadership for the programs related to earth system science. At Earth System Science Organisation (ESSO)-Indian National Centre for Ocean Information Service (INCOIS), he set up a state-of-the-art Early Warning System for Tsunami and Storm Surges in the Indian Ocean and developed a Marine GIS for improving advisory services related to potential fishing zones, ocean state forecast, and Indian Argo project during 2006–08. He had joined the Space Applications Centre, Indian Space Research Organisation (ISRO) in 1978 as a scientist, led coastal and ocean colour research. His current research interest includes building strategy for the blue economy, sustainable development and science diplomacy. He has published about 200 papers in SCI journals. Dr. Nayak is a Fellow of the Indian National Science Academy, New Delhi, Indian Academy of Sciences, Bengaluru, the National Academy of Sciences, India, Allahabad, the International Society of Photogrammetry and Remote Sensing (ISPRS), and Academician of the International Academy of Astronautics, Paris. Considering the impact of his research on the society, the Govt. of India has conferred him the civilian honour 'Padma Shri' in the field of science and engineering in 2024.

Preface

The terms 'Geo-information' and 'Natural Disaster' are commonly used by planners, social scientists, and earth scientists. Geo-information involves analyzing spatial data through computer hardware and specialized software. A natural disaster occurs when natural hazards interact with the man-made environment, resulting in a sudden disruption of the socio-economic fabric of a society. These hazardous processes are inherent to Earth's system and have been interacting with society since time immemorial. Predicting and understanding the dimensions of natural hazards is a challenging task, especially as human activities encroach upon hazardous terrain. Consequently, worldwide damage statistics indicate an increasing trend despite significant investments in natural hazard management techniques.

Advancements in science and technology have significantly enhanced the capabilities of geo-information techniques and tools. Consequently, these techniques are now extensively used in pre-disaster, near real-time, and post-disaster management, enabling effective damage assessment from micro- to meso-scales. The Sendai Framework for Disaster Risk Reduction (2015–2030) strongly advocates for reducing disaster-induced damage and the scale of disasters at regional and global levels. To achieve this, susceptibility to natural hazards is frequently mapped and analyzed using various methods, such as simple weighted overlay (analytical hierarchical process), artificial intelligence, and machine learning techniques. These approaches utilize both physically surveyed and remotely sensed data.

This edited volume aims to offer a comprehensive collection of critical reviews, original articles, and practical case studies on disaster monitoring, suitable for management purposes at local, regional, national, and international levels. The carefully curated articles include hazard zonation maps, scenario maps, and vulnerability maps for various types of disasters. The studies incorporate multiple methods and algorithms, such as random forest, artificial neural network, support vector machine, ordinary least square (OLS) regression, combination matrix analysis (CMA), nonparametric (MK test), and graphical (ITA) test-based MCDA-AHP approach in a GIS environment. These well-established machine learning techniques provide reliable and accurate mapping and prediction of monitored disasters.

The book's primary focus is on disaster monitoring, providing a detailed overview of the integration of geo-information and various methods in this field. It comprises 23 contributed chapters that explore the advancements of geo-information for disaster monitoring and management before, during, and after such events. The book is organized into seven major parts, each containing specific chapters that present knowledge and concepts related to disaster types and their monitoring. It caters to a wide range of readers, including undergraduates, graduates, and researchers, delivering findings in a vivid and accessible manner.

The editors expect this book to be a valuable asset for researchers engaged in disaster-related themes utilizing geo-information technology. By leveraging the methods and technologies presented, researchers can address individual disaster themes scientifically and generate outcomes for disaster monitoring and management. The book offers a concise summary of key case studies, providing the most recent and widely used methods and information, aligning user needs with the appropriate level of technology required for disaster monitoring, management, and planning.

The book serves as a solid scientific foundation for students and researchers to tackle future challenges in disaster research. It also acts as a helpful reference and practical guide for professionals working in disaster-related fields. The contributions from esteemed researchers provide updated knowledge, enriching this edited volume with cutting-edge research and selected case studies on various types of disasters.

Part I: 'General' commences with the opening chapter by editors, Chap. 1, presenting a path for progress and an editorial communication that sheds light on different types of disasters and their categorization. Within this chapter, the emphasis shifts toward the prospective contributions from the authors, along with a concise overview of the content covered in each subsequent chapter. The primary focus remains on disaster monitoring knowledge and the methodologies employed for this purpose.

Part II: 'Geophysical Disasters' consists of six chapters highlighting diverse studies on earthquakes, geo-environmental hazards, landslides, and seismic hazards utilizing both traditional and advanced algorithms.

Part III: 'Hydrological Disasters' encompasses six chapters that delve into rainfall-induced hazards, permafrost, flood susceptibility mapping using a combination of traditional state-of-the-art knowledge and artificial intelligence. This part also explores the use of MCDA approaches for land suitability in flood-prone areas within a GIS environment. Additionally, it presents strategies for emergency response and essential services during floods to mitigate loss of life and reduce damages.

Part IV: 'Meteorological Disasters' comprises one carefully curated chapters providing insights into cyclones. The part showcases recent advances in geo-information for tropical cyclones. It also offers a basic understanding of tropical cyclones, their characteristics, and movements.

Part V: 'Climatological Disasters' includes four chapters that discuss current issues, challenges in forest fires, droughts, and their frequent occurrence. It addresses the use of terminologies in climate resilience studies, synthesizing key concepts and promoting better understanding among researchers. Furthermore, it explores the linkages between forest fires and climatic determinants using techniques like least square

(OLS) regression, increment ratio (IR), and combination matrix analysis (CMA) in a GIS environment.

Part VI: 'Biological and Man-Made Disasters' comprises two chapters that shed light on the environmental conditions and air quality changes post COVID-19, using AQS models. It also presents insights into predicting the occurrence of COVID-19 at spatiotemporal scales using epidemic models with spatial interaction, validated against official epidemiological data. This part covers biological disasters, their prediction, and their prolonged impact on the environment.

Part VII: 'Challenges and Future Opportunities in Disaster Monitoring', the final part of the book, concludes with an overview of challenges and opportunities in disaster monitoring, highlighting the hurdles faced by academia and the potential for extensive devastation, damage, and human suffering. This part also addresses solid waste management resulting from natural or human-induced disasters and emphasizes the use of machine learning techniques to manage such waste across the lithosphere. Lastly, it discusses the lack of monitoring during and after disasters and the need for improved risk assessment to provide more effective relief measures for affected populations.

The editors extend heartfelt gratitude to Shiv Nadar Institution of Eminence (SNIoE), Sikkim University, Chandigarh University, Banaras Hindu University, University of Geneva, and all colleagues for their unwavering support and assistance throughout the progress of this work. Dr. Pandey expresses profound appreciation to his beloved wife and daughter, Adele, for their unwavering support and emotional encouragement during the development of this book's final stage.

Moreover, the editors wish to convey their sincere thanks to the esteemed publisher, Springer, for providing the opportunity to bring together the valuable contributions of several contributors into this book. Special appreciation goes to all the authors for their enthusiastic efforts in delivering high-quality chapters and their cooperation during the screening, review, and copy-editing process. The editors are deeply indebted and thankful to the reviewers who dedicated their time and efforts to review the chapter manuscripts, providing invaluable voluntary support.

We hope that this preface has successfully provided insights into geoinformation technology for different disaster events and the monitoring-related topics covered in this book. We encourage readers to adapt and utilize the content in a manner that best suits their needs, helping them understand the capabilities and potentials of disaster monitoring and its applications, the core focus of this book. Users are welcome to inform the editors of any errors, suggestions, or comments to further improve and enhance the book's content.

Greater Noida, India — Prem C. Pandey
Gangtok, India — Rajesh Kumar
Mohali, India — Manish Pandey
Geneva, Switzerland — Gregory Giuliani
Gangtok, India — R. K. Sharma
Varanasi, India — Prashant K. Srivastava
March 2024

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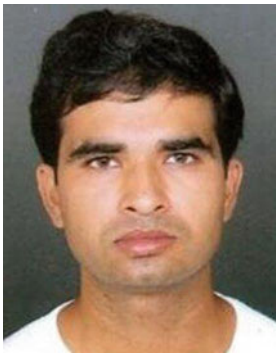
Editors and Contributors

About the Editors

Dr. Prem C. Pandey received his Ph.D. from Centre for Landscape and Climate Research, University of Leicester, UK. He served as Research Scientist at Tel Aviv University, Israel. Currently, he is working as Assistant Professor at Department of Life Sciences, Shiv Nadar Institution of Eminence (Deemed to be University), Uttar Pradesh, India. Previously, he had been associated with IESD, Banaras Hindu University, India. He received his M.Sc. in Environmental Sciences and M.Tech. in Remote Sensing. He worked on remote sensing applications as Professional Researcher funded by NRSC Government of India. He has been a recipient of several awards including The Commonwealth award UK, INSPIRE fellowship, MHRD and UGC fellowships, and SERB-NPDF from GoI India. He has published more than 45 peer-reviewed journal papers, has edited Eight books, several book chapters, and presented his work in several conferences. Additionally, he is a life member of the Indian Society of Geomatics, and the Indian Society of Remote Sensing, as well as a IUCN CEM Member (2017–2021; 2022–2025), International Society of Precision Agriculture (ISPA) and the Society of Wetland Scientists (2021–2022). He is serving as Editorial member for the *Journal-Geocarto International* (Taylor & Francis), *Sustainable Development* (Wiley) and associated with *Remote Sensing* (MDPI) as topic Editor. Dr. Pandey is awarded FGIR (Faculty Grant for Interdisciplinary Research) funded by Shiv Nadar Foundation and Shiv Nadar Institution of

Eminence for the project "Earth Observation of Development Activities in the Hindu Kush Himalaya (HKH) Region and their Impacts on Natural as well as Human Landscapes: Transnational Case Studies". Dr. Pandey is working in three projects related to Monitoring of wetlands/chilika lake mainly focusing on Ramsar sites along with other natural resources based research work funded by NGP and SERB Government of India. Dr. Pandey is also working with science-collaborators for real time disaster monitoring at Himalayan region. He has expertise in remote sensing of environment and natural resources including forestry, agriculture, urban studies, and atmospheric pollutant monitoring, mapping, and modeling.

Dr. Rajesh Kumar successfully received his Ph.D. (Geography) on 'Fluvial Processes in Lower Rapti River Basin: A Case Study of Impacts on Arable Land' from the CSRD, JNU in 2011. He was awarded the Junior Research Fellowship (JRF) in 2009 by the University Grant Commission (UGC), New Delhi. He is currently working as an Assistant Professor in the Department of Geography,Sikkim University, Gangtok, India. He worked as Research Associate in the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (GoI)—sponsored project on 'Ganga River Basin Management Plan' in collaboration with School of Environmental Sciences, JNU and IIT Kanpur during October 2011–July 2013. Further, he joined the CSRD as Research Associate and worked in the Department of Science (DST), GoI-sponsored project on 'Geomorphological and Chronostratigraphic Reconstruction of Glacial Episodes of Gangotri Glacier in Bhagirathi Basin, NW Garhwal Himalaya' from August 2013 to August 2014. He is actively involved in research and wrote 29 research papers/book chapters/Atlas, published by national and international publishers. His major research areas are related to applications of geospatial technology in river science. His research papers are related to the Anthropocene epoch of geological time scale dealing with impact of human activities on rivers and climate-related disasters.



Dr. Manish Pandey is a distinguished researcher currently affiliated with the University Center for Research and Development (UCRD) at Chandigarh University in Mohali, Punjab, India. He completed his undergraduate degree in Geography (with honors) and his postgraduate degree in Geography from the University of Allahabad in Allahabad, Uttar Pradesh, India. Dr. Pandey's exceptional academic journey includes being awarded research grants as a Junior Research Fellow (JRF) and Senior Research Fellow (SRF) by the Council of Scientific and Industrial Research (CSIR), Ministry of Human Resource Development, Government of India, to support his doctoral research. His extensive studies led him to earn a Ph.D. in the field of geomorphology. Following the completion of his doctoral degree, he dedicated over five years to conducting postdoctoral research, holding various research positions. Within the realm of geography, Dr. Pandey possesses a profound interest in Fluvial and Glacial Geomorphology, Glaciology, and Remote Sensing and Geoinformatics (GIS). Notably, he has recently developed a keen interest in applying artificial intelligence, machine learning, and deep learning algorithms to study natural hazards. His research aims to explore how these advanced technologies can enhance our understanding of future land exposure to such hazards. Dr. Pandey's academic pursuits encompass a wide range of environmental settings, with a particular focus on comprehending the process-form relationship. He brings valuable expertise as an experienced research associate with a demonstrated track record in the research industry. His proficiencies include cartography, geomorphology, and extensive knowledge of GIS software such as ArcGIS, QGIS, ERDAS Imagine, and Data Analysis. Additionally, he holds a Doctor of Philosophy (Ph.D.) in Fluvial Geomorphology from Banaras Hindu University. His research endeavors have been further strengthened through practical fieldwork experiences in glaciology and the rigorous training provided by esteemed Indian institutions like the Geological Survey of India. Dr. Pandey has also received specialized geospatial training from institutions like ISRO, acquiring vital skills necessary for his research pursuits. Notably, Dr. Pandey has actively participated in training groups involved in the study of the Himalayan Foreland

Basin deposits, ancient Neogene Siwalik sequences, and modern analogues such as Gangetic Foreland Basin sediment facies. These investigations aim to unravel the role of synsedimentary processes in the evolution of one of the world's significant foreland basin systems. Dr. Pandey's remarkable contributions to scientific literature include the publication of high-quality peer-reviewed research articles in prestigious national and international journals and books. Notable venues for his work include Ecological Indicators, Science of the Total Environments, Advances in Space Research, Frontiers in Earth Science, and more. His publications serve as a testament to his expertise and dedication to advancing the field of geography.

Prof. Gregory Giuliani is the Head of the Digital Earth Unit and Swiss Data Cube Project Leader at GRID-Geneva of the United Nations Environment Programme (UNEP) and a Senior Lecturer at the University of Geneva's Institute for Environmental Sciences. Gregory Giuliani, a Senior Lecturer at the University of Geneva is a geologist and environmental scientist who specializes in Geographical Information Systems (GIS) analyses and Spatial Data Infrastructures (SDI). He also works at GRID-Geneva of the United Nations Environment Programme (UNEP) since 2001, where he was previously the focal point for Spatial Data Infrastructure (SDI) and is currently the Head of the Digital Earth Unit. Gregory's research focuses on Land Change Science and how Earth observations can be used to monitor and assess environmental changes and support sustainable development. Interdisciplinary is a key element for generating new ideas and innovations in his research. He also previously worked as a GIS Consultant for the World Health Organization, as a University tutor in remote sensing and GIS and as a GIS developer in a local Swiss GIS company. After obtaining a degree in Earth Sciences, Gregory went on to complete a master's degree and a Ph.D. in Environmental Sciences, specializing in remote sensing, GIS, and SDI.

Dr. R. K. Sharma is a Glacio-hydrologist working on glacier dynamics and potentially vulnerable glacial lakes in Sikkim Himalaya. He is the Co-Principal Investigator of a nationally coordinated project entitled 'National Mission for Sustaining the Himalayan Ecosystem (NMSHE) Phase II' for the state of Sikkim, supported by the Department of Science and Technology Government of India. Dr. Sharma is also associated in a project with North Eastern Space Applications Centre (NESAC), Shillong for deployment of Early warning system (EWS) for GLOFs in Sikkim Himalaya supported by North Eastern Council (NEC) where he serves as Principal Investigator in the project. His current research interest lies in in-situ based monitoring of glaciers, hazard potential of glacial lake outburst floods (GLOFs), glacial lake management, GLOF hazard mitigation, and early warning systems (EWS) for glacial hazards in the Himalaya. Presently, Dr. Sharma is serving as an Assistant Scientific Officer in the Remote Sensing and Climate Change Division, Sikkim State Council of Science and Technology, Vigyan Bhawan, Government of Sikkim, located at the capital city of Gangtok, Sikkim, India, and has research experience in the field of climate change for more than ten years in Sikkim Himalaya. He has published many scientific research papers on Scopus-Indexed Journals in the field of climate change and forest fires, glacier hydrology, suspended sediment dynamics of the glacial stream, climate change-induced glacial hazards and presented his findings in many national and international conferences. Recently, he has developed a glacial lake volume-area empirical equation for the Indian Himalayan moraine-dammed glacial lakes.

Dr. Prashant K. Srivastava received his Ph.D. from Department of Civil Engineering, University of Bristol, Bristol, UK, sponsored by British High Commission, United Kingdom, under the Commonwealth Scholarship and Fellowship Plan (CSFP) and MHRD, GoI. He received his B.Sc. in Agriculture Sciences from the Institute of Agricultural Sciences, Banaras Hindu University (BHU), and his M.Sc. in Environmental Sciences from School of Environmental Sciences (SES), Jawaharlal Nehru University (JNU), India. Currently he is working as an Assistant Professor at the Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India. He is the recipient of several awards such as NASA Fellowship, United States of America; University of Maryland Fellowship, United States of America; Commonwealth Fellowship, United Kingdom, and received JRF-NET fellowships from Council of Scientific and Industrial Research and University Grant Commission, Government of India. He is leading many national and international projects funded by reputed agencies. He has published over 140 peer-reviewed journal papers, seven books, many book chapters, and has presented his work in several conferences. Currently, he is also serving as Associate editor of many scientific peer-reviewed journals. He is also a member of European Geosciences Union (EGU), Indian Society of Geomatics, Indian Society of Remote Sensing, Indian Association of Hydrologists (IAH), and International Society for Agro-meteorology (INSAM), International Association for Hydro-Environment Engineering and Research (IAHR), and International Association of Hydrological Sciences (IAHS).

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Acronyms

°	Degree
°C	Degree Celsius
°F	Degree Fahrenheit
3DP	3D printing
A2C	Advantage Actor-Critic
A3C	Asynchronous Advantage Actor-Critic
AAR	Accumulation area ratio
ABS	Acrylonitrile butadiene styrene
AHP	Analytical hierarchy process
AI	Artificial intelligence
ALT	Active layer thickness
AM	Additive manufacturing
ANN	Artificial neural network
ANNs	Artificial neural networks
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
ARR	Annual rainfall ratio
AS	Arabian Sea
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
Avg.LPA_{33}	Annual average rainfall of 33 years (1990–2022)
$Avg.R_{\text{D}}$	Annual average rainfall at district level during recent decade
AWMI	Aggregate Weighted Mean Index
BOB	Bay of Bengal
C	Cohesion
CA2C	Continuous Action Actor-Critic
CCA	Climate change adaptation
CD	Cyclone depressions
CDRI	Climate Disaster Resilience Index
CEM	Cross-entropy method
CFC	Circular failure chart

CFSR	Climate forecast system reanalysis
CI	Consistency Index
CMA	Combination matrix analysis
CMT	Centroid moment tensor
CNNs	Convolutional neural networks
COOLR	Cooperative Open Online Landslide Repository
CPAP	Continuous positive airways pressure
CPC	Climate prediction center
CR	Consistency ratio
CRD	Climate resilient development
CRDPs	Climate resilient development pathways
CRI	Climate Resilience Index
CRU	Climate Research Unit
CS	Cyclonic storms
CV	Coefficient of variation
D4PG	Distributed Distributional Deterministic Policy Gradients
DA	Disaster assessment
DBSCAN	Density-based spatial clustering of applications with noise
DDPG	Deep deterministic policy gradient
DED	Direct energy deposition
DEM	Digital elevation model
DL	Deep learning
DM	Disaster management
DQNs	Deep Q-Networks
DRP	Deviation of rainfall in percent
DRR	Disaster risk reduction
DSA	Dry sieve analysis
DST	Direct shear test
DTM	Digital terrain model
DWM	Disaster waste management
E	East
ELA	Equilibrium line altitude
ENVIS	Environmental Information System
ES	Evolution strategies
ETM	Enhanced thematic mapper
FDM	Fused deposition modelling
FEM	Finite element method
FEMA	Federal Emergency Management Agency
FFC	Forest fire count
FFD	Forest fire density
FFEWS	Flood forecasting and early warning system
FFF	Fused filament fabrication
FOS	Factor of Safety
FR	Frequency ratio
FRA	Flood risk assessment

FSI	Forest Survey of India
g	Number of groups with similar values
G	Grid
G(X)	The cumulative probability
GBM	Gradient boosting machines
GEO-5	Global Environment Outlook
GHG	Greenhouse gases
GIS	Geographical Information System
GLC	Global landslide catalog
GLOFs	Glacial lake outburst floods
GMM	Gaussian mixture model
GMPE	Ground motion prediction equation
GNNs	Generative adversarial networks
GoS	Government of Sikkim
GPS	Global Positioning System
GSI	Geological Survey of India
H(x)	Cumulative probability
HFL	High flood level
HKT	Himalayan Karakoram Tibet
HMA	Hot mix asphalt
IAEG	International Association for Engineering Geology and the Environment
ICA	Independent component analysis
ICAR	Indian Council of Agricultural Research
ICIMOD	International Centre for Integrated Mountain Development
IEDM	International Environment and Disaster Management
IMD	The India Meteorological Department
IoT	Internet of Things
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change
IPRD GoS	Information and Public Relations Department, Government of Sikkim
IR	Increment ratio
IRS	Indian Remote Sensing Satellites
ISRO	Indian Space Research Organization
ITA	Innovative trend analysis
IUCN	International Union for Conservation of Nature
JFM	January, February, March
JFMC	Joint Forest Management Committee
k-NN	k-nearest neighbors
LCL	Lifting condensation level
LDA	Latent Dirichlet allocation

LDPE	Low-density polyethylene
LHASA	Landslide Hazard Assessment for Situational Awareness
LI	Landslide inventory
LIA	Little Ice Age
LII	Landslide inventory incompleteness
LISS	Linear Imaging and Self-Scanning Sensor
LLE	Locally linear embedding
LOM	Laminated object manufacturing
LPA_{30}	Annual average rainfall of 30 years (1993–2022)
LR	Logistic regression
LSA	Land suitability analysis
LSI	Land Suitability Index
LSM	Landslide susceptibility map
LSTM	Long short-term memory
LULC	Land use/Land cover
M	Moderate rainfall
M.P.	Madhya Pradesh
MANU	Map the Neighborhood in Uttarakhand
MCDA	Multi-criteria decision analysis
MCEER	Multidisciplinary Center for Earthquake Engineering Research
MCT	Main Central Thrust
MFCs	Microbial fuel cells
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MHT	Main Himalayan Thrust
MK	Mann-Kendal test
ML	Machine learning
MLP	Multilayer perceptron
MODIS	Moderate resolution imaging spectroradiometer
MoEFCC	Ministry of Environment, Forest and Climate Change
MSS	Multispectral scanner system
MSW	Municipal solid waste
MTOWQ	Mean temperature of warmest quarter
Mw	Moment magnitude
n	Number of years selected for analysis
N	North
NASA	National Aeronautics and Space Administration
NbS	Nature-based solutions
NCEP	National Center for Environmental Prediction
NDMA	National Disaster Management Authority
NDMC	National Drought Mitigation Center
NDVI	Normalized Difference Vegetation Index
NDW	Natural disaster waste
NDWM	Natural Disaster Waste Management
NE	North East
NER	Northeastern region