GEOMORPHOLOGICAL HAZARDS IN KOHIMA DISTRICT OF NAGALAND: A GEOSPATIAL APPROACH

by

KHRIEKETOUNO BELHO

Submitted to

NAGALAND UNIVERSITY

In Fulfilment of the Requirement for Award of the Degree

of

DOCTOR OF PHILOSOPHY IN GEOGRAPHY

DEPARTMENT OF GEOGRAPHY

NAGALAND UNIVERSITY

LUMAMI-798627

NAGALAND, INDIA

2024

Dedicated to

my mother, ***AZONUO LUCY BELHO*** *and*

my sister, ***NEITHONGUNUO ANGELA BELHO***

Who has always been my stronghold.

NAGALAND UNIVERSITY

(A Central University Estd. By the Act of Parliament No. 35 of 1989)
DEPARTMENT OF GEOGRAPHY
School of Sciences, Nagaland University, Lumami-798627

E mail:msrawat@nagalanduniversity.ac.in
msrckr@gmail.com
Mobile:8630906738
9612292496

Dr. M. S. Rawat,
Professor

Date: 05/08/2024

CERTIFICATE

This is to certify that the Ph.D. thesis entitled "**GEOMORPHOLOGICAL HAZARDS IN KOHIMA DISTRICT OF NAGALAND: A GEOSPATIAL APPROACH**" submitted by Miss Khrieketouno Belho, Research Scholar in the Department of Geography, School of Sciences, Nagaland University, Lumami bearing Regd. No. Ph.D/GEO/00079 dated 31/08/2017, for the degree of Doctor of Philosophy in Geography of this University is her original work and personal investigations. According to the best of my knowledge, this thesis has not been submitted for the award of any other degree of this university or any other university.

I recommend that this thesis may be placed before the examiners for evaluation for the award of the Ph.D. Degree in Geography of this University.

05/08/2024
(Prof. M.S. Rawat)
Supervisor

5.8.2024
(Prof. Wangshimenla Jamir)
Head of the Department

HEAD
Department of Geography
Nagaland University, Lumami

NAGALAND UNIVERSITY

(A Central University Estd. By the Act of Parliament No. 35 of 1989)
DEPARTMENT OF GEOGRAPHY
School of Sciences, Nagaland University, Lumami-798627

Date: 05/08/2024

DECLARATION

I, Miss Khrieketouno Belho, bearing Ph.D. registration no. Ph.D/GEO/00079 dated 31/08/2017 do hereby declare that my Ph.D. thesis entitled, "**GEOMORPHOLOGICAL HAZARDS IN KOHIMA DISTRICT OF NAGALAND: A GEOSPATIAL APPROACH**" is the record of work done by me, and that the contents of this thesis does not form the basis for award of any previous degree to me or to anybody else known to the best of my knowledge. This Ph.D. thesis have not been submitted by me for any other research degree in any other university/ institute.

This thesis is being submitted to the degree of "Doctor of Philosophy in Geography", Nagaland University, Lumami.

05/08/2024
(Miss Khrieketouno Belho)
Ph.D. Candidate

05/08/24
(Prof. M.S. Rawat)
Supervisor

5.8.2024
(Prof. Wangshimenla Jamir)
Head of the Department

HEAD
Department of Geography
Nagaland University, Lumami

नागालैण्ड विश्वविद्यालय
NAGALAND UNIVERSITY

(संसद द्वारा पारित अधिनियम 1989, क्रमांक 35 के अंतर्गत स्थापित केंद्रीय विश्वविद्यालय)
(A Central University established by an Act of Parliament No.35 of 1989)
मुख्यालय : लुमामी | Headquarters : Lumami

PLAGIARISM FREE UNDERTAKING
साहित्यिक चोरी मुक्त शपथ-पत्र

Name of Research Scholar/Student शोधार्थी/विद्यार्थी का नाम	KHRIEKETOUNO BELHO
Ph.D/M.Phil. Registration Number पीएच.डी/एम.फिल. पंजीयन संख्या	Ph.D/GEO/00079 (31/08/2017)
Title of Ph.D thesis /M.Phil. Dissertation पीएच.डी थीसिस/एम.फिल. शोध-प्रबंध का शीर्षक	GEOMORPHOLOGICAL HAZARDS IN KOHIMA DISTRICT OF NAGALAND: A GEOSPATIAL APPROACH
Name & Institutional Address of the Supervisor/Joint Supervisor शोध-निर्देशक/सह शोध-निर्देशक का नाम व संस्थानिक पता	PROF. M.S. RAWAT DEPARTMENT OF GEOGRAPHY NAGALAND UNIVERSITY
Name of the Department/School विभाग/संकाय का नाम	DEPARTMENT OF GEOGRAPHY, SCHOOL OF SCIENCES, N.U., LUMAMI
Date of Submission प्रस्तुत करने की तिथि	
Date of Plagiarism Check साहित्यिक चोरी की जांच की तारीख	06-08-2024
Percentage of similarity detected by the DrillBit software ड्रिलबिट सॉफ्टवेर द्वारा खोजी गई समानता का प्रतिशत	5%

I hereby declare/certify that the Ph.D Thesis/M.Phil. Dissertation submitted by me is complete in all respect, as per the guidelines of Nagaland University (NU) for this purpose. I also certify that the Thesis/Dissertation (soft copy) has been checked for plagiarism using **DrillBit** similarity check software. It is also certified that the contents of the electronic version of the thesis/dissertation are the same as the final hardcopy of the thesis/dissertation. Copy of the Report generated by the **DrillBit** software is also enclosed.

मैं एतद् द्वारा घोषित/प्रमाणित करता/करती हूं कि पीएच.डी. थीसिस/एम.फिल. इस उद्देश्य के लिए नागालैंड विश्वविद्यालय (एनयू) के दिशा-निर्देशों के अनुसार मेरे द्वारा प्रस्तुत शोध प्रबंध सभी प्रकार से पूर्ण है। मैं यह भी प्रमाणित करता/करती हूँ कि थीसिस/शोध-प्रबंध (सॉफ्ट कॉपी) को **ड्रिलबिट** समानता जाँच सॉफ्टवेयर का उपयोग करके साहित्यिक चोरी के लिए जाँचा गया है। यह भी प्रमाणित किया जाता है कि थीसिस / शोध-प्रबंध के इलेक्ट्रॉनिक संस्करण की सामग्री थीसिस / शोध-प्रबंध की अंतिम हार्डकॉपी के समान है। **ड्रिलबिट** सॉफ्टवेयर द्वारा तैयार की गई रिपोर्ट की प्रति भी संलग्न है।

06/08/2024
(Name & Signature of the Scholar)
(शोधार्थी का नाम व हस्ताक्षर)
KHRIEKETOUNO BELHO

Date/दिनांक : 06-08-2024
Place/स्थान :

Prof. M.S. Rawat
Department of Geography
Nagaland University, Lumami
School of Sciences
Nagaland University
Hqs. Lumami Nagaland

Name & Signature of the Supervisor (With Seal):
शोध-निर्देशक का नाम व हस्ताक्षर (मुहर सहित)

Name & Signature of the Joint-Supervisor (With Seal) (If any) :
सह शोध-निर्देशक का नाम व हस्ताक्षर (मुहर सहित) (यदि कोई)

DrillBit

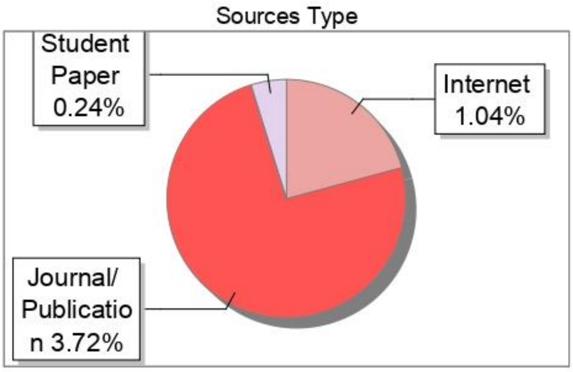
The Report is Generated by DrillBit Plagiarism Detection Software

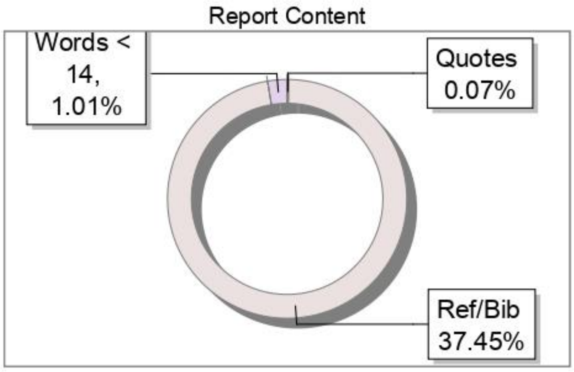
Submission Information

Author Name	Khrieketouno Belho
Title	Geomorphological Hazards in Kohima District of Nagaland: A Geospatial Approach
Paper/Submission ID	2226986
Submitted by	msrawat@nagalanduniversity.ac.in
Submission Date	2024-08-13 14:22:10
Total Pages, Total Words	337, 87718
Document type	Thesis

Result Information

Similarity **5 %**





Exclude Information

Quotes	Excluded
References/Bibliography	Excluded
Source: Excluded < 14 Words	Not Excluded
Excluded Source	**0 %**
Excluded Phrases	Not Excluded

Database Selection

Language	English
Student Papers	Yes
Journals & publishers	Yes
Internet or Web	Yes
Institution Repository	Yes

A Unique QR Code use to View/Download/Share Pdf File

Acknowledgement

I take this opportunity to lay down my humble gratitude to everyone who has played a significant part in enabling me in completing my research work for the degree of Doctor of Philosophy in Geography. It has been a period of unseen challenges and delight as I delved into this academic quest and I thank my Lord Almighty to whom I simply owe everything.

I have been extremely blessed to have been allotted with Dr. M.S. Rawat, Professor, Department of Geography, Nagaland University, Lumami, as my Supervisor. I record my heartfelt gratitude to him for the matchless guidance, encouragement, patience, sincerity and sacrifice he has unceasingly offered to me. His valuable advices have been the backbone of the success of my research.

I am also very deeply indebted to Dr. Pradeep Kumar Rawat, Consultant Professor, Asian International University, Imphal, Manipur (India) for the tremendous help and guidance he has given me over the course of my research. The untiring efforts and knowledge he has offered me remains one of the few special things I will remain ever grateful for.

Many people have facilitated the initiation of this investigation and I specially thank all the faculties and staffs of the Department of Geography, NU, Lumami. Prof. Wangshimenla Jamir, Head of the Department, Prof Sangyu Yaden, Prof Lanusashi Longkumer, Dr. Kedovikho Yhoshii, Assistant Professor, and Dr. Manasi Debnath, Assistant Professor, for their unfailing support and valuable advices over the course of my research. I also extend my heartfelt gratitude to Dr. P. Toiho Sema, Sr. Technical Assistant, Ms. Achila, former LDC, Mr. Khekaho, LDC, Dr. Brenda, Lab Assistant, Mr. Meso Khiamniungan, Lab Attendant and Mr. Toshimongba, Field Attendant for their perfect coordinated backup at all times.

My utmost gratitude to the University Grants Commission UGC Non-NET fellowship and the Ministry of Tribal Affairs- National Fellowship for ST Students for the financial assistance that had been granted to me which has greatly facilitated the smooth flow of my research.

I thank the Indian Meteorological Department, CSIR- North East Institute of Science and Technology, Jorhat, Nagaland State Disaster Management Authority (NDMA), Kohima,District Disaster Management Authority (DDMA)-Kohima, Nagaland GIS and Remote Sensing Center, Kohima, Directorate of Soil and Water Conservation, Kohima, Department of Irrigation and Flood Control, Kohima, Directorate of Geology and Mining, Dimapur, Geological Survey of India, Dimapur, Department of Geology, Nagaland University, Meriema and other departmental institutions and offices that has rendered their valuable services in providing me with the necessary meteorological, seismic, disaster and other recorded required data for the research.

My sincere gratitude is extended to Mr. Rupesh Sebastian, Mr. Limasanen Jamir, Mr. Vizovol Kirha, Mr. Aochuba Longkumer and Mr. Methatso Ltu for rendering their unconditional help during the course of field work and collection of primary data. The research would not have been successful if it were not for the unconditional service they have offered.

I also thank the galaxy of supportive friends and fellow research scholars which have always been a source of inspiration and encouragement. I also acknowledge and thank each and every individual who have prayed and wished me well as I embarked on this journey.

Lastly, the unceasing support and endless prayers of *my mom* and *my sister* remains the secrets of all my successes for which I will always remain highly indebted.

(KHRIEKETOUNO BELHO)

CONTENTS

List of Figures

List of Tables

List of Plates

INTRODUCTION

Geography simply means the study of the earth. It is a discipline which studies the relationship between man and the environment in its entirety. Geography describes and analyzes the spatial variations in physical, biological, and human phenomena that occurs on the surface of the earth. Likewise, this subject considers their interrelationships and their significant regional patterns (Katupotha, 2004). Geography, right from its beginning deals with the man-environment relationship in spatial context and today it has become an interdisciplinary science concerned with the surface of the earth and its natural environment as well as the human intervention which has changed the physical and cultural landscape over the years (Saxena, 1999). The study of Geography enables an individual to grasp the explanatory ability of spatial phenomenon. Geography is said to have now acquired the status of science that explains the arrangement of various natural and cultural features on the earth surface. It is branched out into Physical Geography which studies the spatial patterns, processes and interrelationships in the natural environment, Human Geography, which explains the spatial aspects of human cultures, settlements and the human use of the earth's environment and Regional Geography which includes the study of physical and human geography of defined world regions.

Geomorphology, the scientific study of landforms and the processes that shape them, is an important branch of Physical Geography. Geomorphology has grown into a discipline having several specialized fields for example, structural geomorphology, tectonic geomorphology, quantitative geomorphology, applied geomorphology and environmental geomorphology. The knowledge of local geomorphology is being used increasingly for avoiding environmental degradation which mitigates natural hazards such as floods and landslides and for environmental management planning (Kale and Gupta, 2001). The beginning of the modern geomorphological thought and practice is attributed to several scholars towards the end of the eighteenth and the beginning of the nineteenth century. Earlier too, there were several advances to the science of geomorphological knowledge. Here, it is not necessary to review such advances in detail. In hindsight, the cycle of erosion was a theory of its time. It did neither significantly advance the science of geomorphology nor provided the geomorphologists with any tool for applied work. The arrival of what is now called process geomorphology in the 1950s was a revolutionary breakthrough. In geomorphology, a process is a continuous set of natural actions that changes landforms and sediment. Study of processes therefore is basic in geomorphology in order to understand landforms to explain the on-going changes and to predict future patterns.

A science attains meaning when it serves humanity. It becomes useful when it helps in identifying and solving the problems faced by human society arising out of interactions of human activities and environment. Geomorphology is one such science which affects all aspects of human activity. Application of geomorphology in natural hazards comes from simultaneous understanding of geomorphology and comprehension of specific problems to be solved. The aims of applied geomorphology are to assist in the efficient discovery, assessment and wise management of the earth's finite resources, to prevent environmental deterioration and to avoid or prevent natural hazards (Enayat, 1985). The application of geomorphological techniques and the results of geomorphological investigations for resource evaluation, socio-economic development and mitigation and management of natural hazards and disasters are significant aspects of applied geomorphology which should be taken into consideration by the geomorphologists (Das et.al., 1996). Survey of natural hazards, landslides, avalanches, earthquakes, vulcanism, land subsidence, flooding and droughts and natural hazard reduction are the important areas of study in applied geomorphology (Verstappen, 1983).

Several branches of applied geomorphology have been developed during the last few decades viz. environmental geomorphology, urban geomorphology and anthropo-geomorphology which are directly related to the responses of interactions of man with certain sets of geomorphic environmental systems and remedial measures for tackling the problems arising out of those responses (Singh, 2007). Environmental geomorphology deals with the impact of natural processes (e.g., vulcanism, earthquake, floods and droughts, landslides, denudation processes etc.) on human activities and cultural landscapes on the one hand, and the manipulative impact of human activities on the natural environmental processes, problems arising out of these interactions and remedial measures thereof leading to environmental management and natural disaster reduction on the other hand (Singh, 2007). Many researchers have dealt with environmental geomorphology, in the discussion of both specific topics and the various applications of geomorphology in the form of applied geomorphology which involves issues and themes such as i) The study of geomorphological processes and terrain that affect man, including hazardous phenomena such as floods and landslides, ii) The analysis of problems where man plans to disturb or has already degraded the land-water ecosystem iii) How the science of geomorphology can be used in environmental planning and management (Rawat, 2011). A significant portion of the existing understanding about the efficacy of various geomorphic processes—especially mass movement processes—has come from field observations conducted in the mountains. Precise measurements of actual geomorphic processes remained a rarity. Any alteration, whether natural or caused by humans, that might jeopardize a landform's geomorphic stability in the face of biological adversity is referred to as a geomorphological hazard. (Chorley et.al., 1985). Geomorphological hazards range from very long-term hazard (e.g. crustal instability caused by earth movements leading to mountain building, faulting, folding, warping, subsidence, upliftment; by changes in vegetation cover and type and hydrological regime due to climatic changes) to short-term hazards (e.g. volcanic eruption, earthquakes, floods, landslides, avalanches, riparian decay, changes in discharge sediment load and run-off of a river (Singh, 2007). Hazard is an unexpected or uncontrollable phenomenon of unusual magnitude which occurs in proximity and poses a threat to people, structure and economic assets caused by biological, geological, seismic, hydrological, geomorphological or meteorological conditions or processes in natural environment. Though the root cause of most of the natural hazards are associated with natural processes, the degree and intensity of a hazard is very much dependent on man made changes in the environment. Hazards include both natural and man induced which have the tendency to turn into disasters and affect the earth's stability and disturb its morphology. A natural hazard refers to the manifestation of a natural condition or phenomena that poses a danger or operates in a hazardous manner within a certain area and timeframe. (Ayala, 2002). Natural hazards are defined as phenomena that pose a danger and inflict damage to both the physical and social components of life, both immediately and in the long term, owing to their resulting repercussions. It is when these hazards actually affect the daily lives of man, it becomes a disaster and becomes an urgent need for disaster management. Global climate change coupled with an increasing world population; provide a sufficient rationale for the continued research of natural hazards (Hibbeler, 2007). It has been stated by Rosenfeld in 1994 that the global damage caused by natural disasters "increased three-fold from the 1960's through the 1980's leaving more than 3 million dead and causing the displacement of more than 800 million people during that period" (Rosenfeld, 1994). Natural hazards are primarily categorized as geological and hydrometeorological phenomena, including earthquakes, volcanoes, floods, landslides, storms, droughts, and tsunamis. These dangers have a strong correlation with geomorphology since they have a significant role in the dynamics of the Earth's surface (Ayala, 2002).

Kapur (2009) notes that India tops the list of the number of disasters in the world, pointing out that about 59 million people were affected by hazards and disasters in about two decades, during 1982- 2001. The Himalayan Mountains including the North-East hill region of India is increasingly getting affected by geomorphic and hydrometeorological hazards in recent years. The North-East region is characterized by a distinctive geo-environmental setting, a powerful monsoon regime, fragile geological formation, frequent seismic activity, rapid erosion, fast accumulation of sediment in rivers, extensive deforestation, high land use pressure, and extensive construction of roads in hilly areas. These factors contribute significantly to the severity of geo-hydrometeorological hazards in the region. Nagaland and its neighboring states in the North-East India have been placed in the zone 'V' in the earthquake zoning map of India, which is the highest earthquake risk zone magnitude and may even exceed 8.0 in the Richter scale.

Geo-hydrological events such as landslides, debris flows and floods are recurrent natural phenomena that contribute to shaping the earth's morphology and landscapes (Rawat et. al., 1992). These frequent natural events are the result of mostly natural processes that become a hazard when they interfere with the human environment i.e., with the population structure, the infrastructures, the societal interests and the economic assets. Landslides, debris flows, floods and flash floods are caused chiefly by meteorological events including intense or prolonged rainfall (Rawat, 2017). The second-leading cause of death in mountainous regions, after earthquakes, is landslides and the debris flows they cause. Nagaland and its highways are sensitive to landslides. At the national level it is estimated that annually on an average of about 300 human lives are lost and approximately Rs. 300 crores are lost every year. Rs. 350 million is lost due to failure of transportion and communication caused by landslides and about 50% of the landslides occurs along the roads. Applied geomorphology is being used extensively for natural hazard studies and their mitigation and management. It is therefore necessary to develop our knowledge of geomorphological hazards in the north-eastern hills in general and Nagaland in particular.

1.1. Statement of the Problem

In the study of Geography, the concern for hazards and disasters has been increasing ever since its inception as a field of study. Geomorphological hazards are part of a larger group of natural hazards, including floods, slope movements, soil erosion, water quality risk, desertification, sudden weather changes and wildfires (Demek et.al., 2006). Geomorphological hazards are apprehended as a possible occurrence of extremely dynamic or large-area destructive geomorphological process in a particular place and time (Panizza, 1986; Kalvoda, 1996). Geographical perspective of geomorphic hazards includes the hazards distribution, place, processes, location, relationships, movement, clusters, accessibility, patterns, connections and changes. Geomorphic hazards occur due to the instability of the surface features of the earth and results from any landform change that adversely affects the geomorphic stability of a site and that intersects the human use system with adverse socio-economic impacts (Slaymaker, 1996). Ayala stated that between 1990 and 1999, 2808 disasters were recorded worldwide out of which 84% of it were related to geomorphology.

Geomorphic knowledge helps in the identification, prediction and assessment of probable effects and management of geomorphological hazards. The geodynamically active and ecologically sensitive- the North-East hill region of India is facing massive slope failures, subsidence and frequent landslides. The region is also extremely vulnerable to hazards that results from earthquakes and neo-tectonics. Almost all the watersheds and sub-watershed are under constant threat of mass wasting and erosion caused by natural processes, deforestation, jhum practices and other developmental activities. The mass movement, landslides and soil erosion have been the core subject matter of geomorphological hazards. The present study also identified 3-4 small sample watersheds within the study area for the detailed studies by using different tools and techniques. Though every part of the world is susceptible to one or the other types of natural hazards owing to its natural settings as well as owing to its technological interventions, the hilly regions of Northern India fall under one such region which is always at a frequent risk of intense disaster, which maybe in a slow or a fast rate. Kohima, is one such district in the Nagaland state of North-East India, which is very vulnerable to disasters not only because of its steep and rugged terrain which contributes largely to all the hazards the region is at risk of but also because of the very poor planning of developmental activities from the construction of buildings to the construction of roads and lack of proper planning and implementation of disaster management activities.

Table 1.1: The Context of Geomorphic Hazards (after K.J Gregory and John Lewin, 2014).

Sphere	Sub-sphere	Hazard group	Hazards
Atmosphere			Near Earth Objects (NEOs): Comets and asteroids, nudged by the gravitational attraction of nearby planets into orbits allowing them to enter the Earth's spheres. Composed mostly of water ice with embedded dust particles; see http://neo.jpl.nasa.gov/neo/
		Climatic and meteorological	Drought, hurricanes, tornadoes, lightning and severe thunderstorms, hailstorms, snow storms, frost hazards.
	Noosphere Anthroposphere	Technological or man-made hazards	Including environmental degradation, pollution and accidents, associated with complex emergencies/conflicts, famine, displaced populations, industrial accidents and transport accidents.
Hydrosphere		Hydrological	Extreme events associated with water occurrence, movement, and distribution, tsunamis, storm surges, floods and flash floods, droughts.
	Geosphere	Geomorphic	Earth surface dynamics including landform change and process extremes that can adversely affect the site stability and produce adverse socio-economic impacts. Endogenetic – volcanism, neotectonics. Exogenetic – mass movement (snow avalanche), fluvial (floods, channel erosion, sedimentation), karst (collapse), coastal (erosion, tsunamis). Other spheres with consequences for the Earth's surface systems.
Biosphere		Biological	Exposure of living organisms to germs and toxic substances, epidemics, insect infestation, locusts, animal stampede, fungal diseases, poisonous plants, viral diseases.
Lithosphere		Geohazards, Geological, Geophysical	1. Seismic activities occurring deep under the Earth's crust, such as earthquakes, tectonic movements, salt tectonics, and volcanic inflation/deflation. 2. Geological phenomena that might cause ground instability include landslides, soil creep, ground breakdown, collapsible ground, and flowing sand/liquefaction. 3. Ground movement caused by natural factors such as shrink-swell clays and compressible ground. 4. Human-induced ground instability may occur due to many activities such as managing groundwater levels by shallow compaction, managing groundwater levels by oxidizing peat, extracting groundwater, mining, subterranean construction, the presence of man-made ground, and oil and gas extraction.

According to table 1.1, the context of geomorphic hazards after K. J Gregory and John Lewin, 2014, geomorphological hazards have its source depending on the different spheres of the earth, i.e., the atmosphere, the hydrosphere, the biosphere and the lithosphere. The geomorphological hazards that are prevalent in Kohima are earthquakes, landslides, soil erosion and flash floods which occurs as result of the mechanism among the 4-spheres.

Though, geomorphological hazards refer to the hazards that are prevalent on land (lithosphere), it is important to note that it occurs due to the various impacts from the atmosphere i.e., the climate, the hydrosphere i.e., the water bodies such as streams and rivers in the case of Kohima and the biosphere referring to the human interference in the form of developmental activities. Kohima is highly susceptible to geomorphological hazards mainly- Earthquake, Soil Erosion, Landslide and Flash Floods and these hazards are attributed to both physical factors and anthropogenic factors which are discussed in detail in the proceeding chapters:

- **Physical Factors**: Tectonically active geology, rugged and steep terrain, dynamically changing geomorphology, high density of drainage system, heavy monsoonal downpour
- **Anthropogenic factors**: Growing population, rapid unplanned urbanization, degrading land use system and lack of proper disaster management policy.

Table 1.2**:** Total number of geomorphological hazards that caused calamities in Kohima from 15th May 2017 to 29th August 2018 (Source: District Disaster Management Authority, Kohima, 2018).

Sl. No.	**Sub-Division**	**No. of geomorphological calamities**
1	Chiephobozou	19
2	Kohima Sadar	45
3	Sechu Zubza	12
4	Jakhama	14
5	Kezocha	9
	Total	**99**

According to reports from the District Disaster Management Authority (DDMA), Kohima has experienced a total of 99 reported geomorphological hazards over the course of 15 months from 15 May 2017 to 29 August 2018, which depicts the severity of the condition of Kohima in the case of disaster particularly that of geomorphological hazards. Therefore, Kohima district of Nagaland has been selected as the study area for the present study. This work may have sufficient exposure to modern geomorphology to appreciate and understand more of the wonders of nature and realize the geomorphology's ability confers to the practitioner in managing certain aspects of the local environment. Therefore, a study on the geomorphological hazards and their risk assessment have been necessary to propose better mitigation measures and hazard preparedness so that this study would play a significant role as a Decision Support System (DSS) for improvised disaster management system in the district for the well-being of all at the government, community, and individual household levels.

1.2. The Study Area

Kohima is a hilly district in India's North-Eastern state of Nagaland sharing its borders with Chumoukedima and Niuland district in the west, Phek district in the east, Tseminyu district in the north and Manipur state and Peren district in the south with a total area of 978.96 sq km representing 5.90% of the total area of the state of Nagaland. It is the capital of Nagaland and lies between 25º31'21.48" N to 25º54'30.06" N Latitudes and 93º54'17.16" E to 94º16'03.78" E Longitudes with an elevation of 1261meters above mean sea level. Kohima experiences heavy rainfall during monsoon and its average annual rainfall is 2500mm. The temperature rises to 32ºC during the peak summer and reaches to 2ºC during the winter. The main river flowing in the district is the Diyung River which originates in the southern part of the district and flows northward. Another important river is the Dziidza River. The district has a population of 267,988 according to 2011 census. The population of Kohima is ever increasing year after year and also is its developmental activities. It is geographically placed in an unstable part of India as the area is under constant seismic activity. Also, it is one of those places which are extremely rich in biodiversity.

Kohima district is susceptible to geomorphic hazards. The primary factors responsible for this phenomenon are mostly associated with youthful geological formations, steep slopes and topography, intense precipitation, and inadequate land management techniques. The soil is composed of sedimentary materials and has a high level of porosity, making it very prone to erosion and landslides. The research region consists of tertiary rocks from the Disang and Barail groups, which are mostly composed of sandstone and shale. The study area comprising a relatively immature mountainous terrain and representing part of the northern extension of the Arakan Yoma range of Cretaceous- tertiary age is a tectonically complicated area. Climate change in the area has also become a major cause of disruption in the environment with extreme rainfall in a short period of time and prolonged days of no rainfall causing drought-like conditions giving rise to water shortages and a negative impact on the agricultural and allied sectors of plantation. Also, rapid increase in population and concentration of population in hazardous areas, lack of a proper scientifically backed-up developmental activities, and lack of a rigid planning and policies on disaster management has led to the severity and escalation of hazards in the region. Besides danger to human and livestock, business and other establishments are highly vulnerable, especially at and along the highways of Kohima as disruption of roads is a common phenomenon in the district of Kohima.

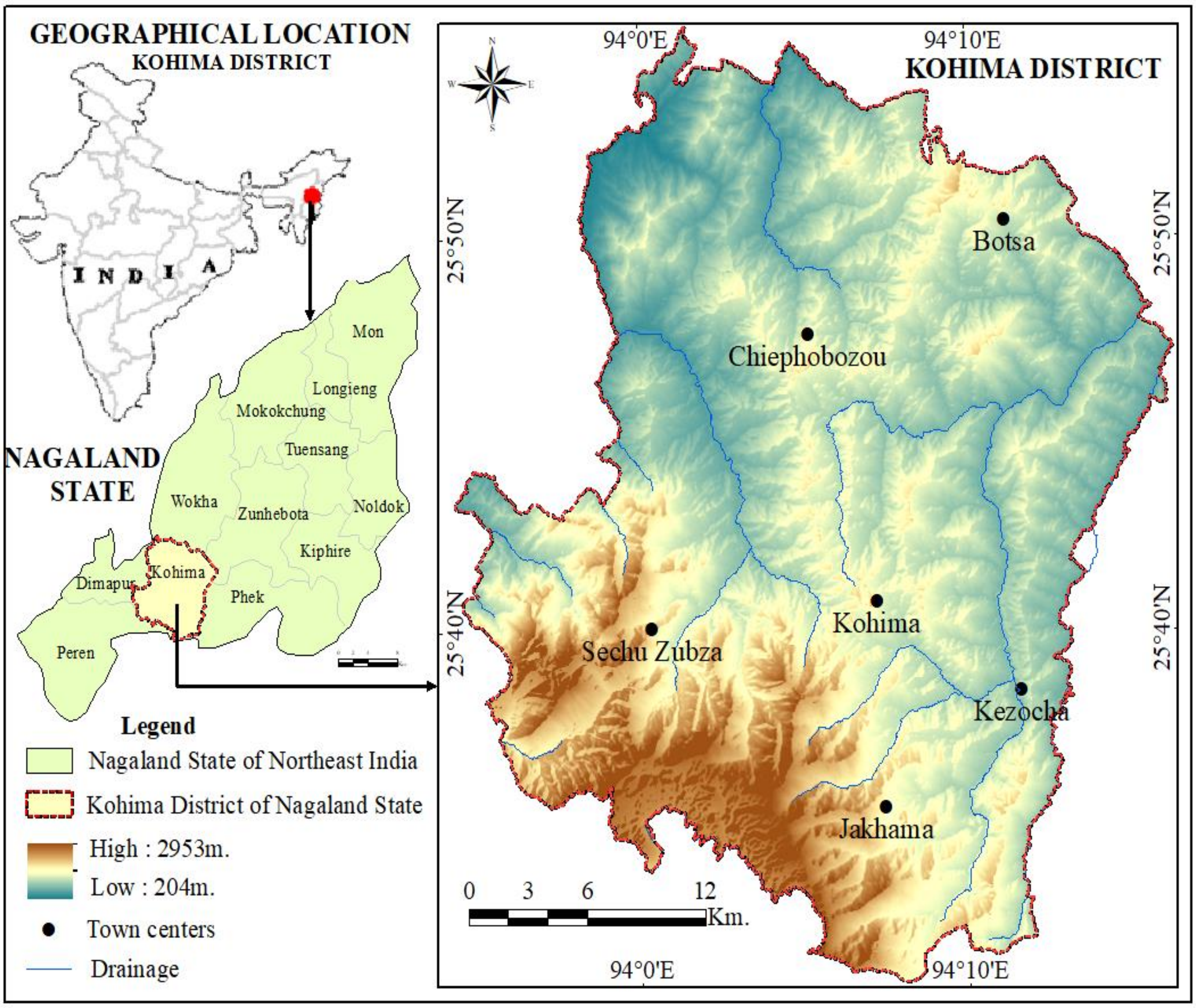


Figure 1.1: Location Map of the Study Area i.e., Kohima district of Nagaland, India.

1.3 . The Objectives of the Study

i) To study the environmental geomorphology of Kohima district

ii) To identify the geo-hydrological processes in the study area

iii) To assess and map the geomorphological hazards

iv) To analyze the community and government-based disaster management activities and programs

v) To propose strategy for mitigation and management of geomorphological hazards of Kohima district in particular and Nagaland in general

1.4 . Methodology

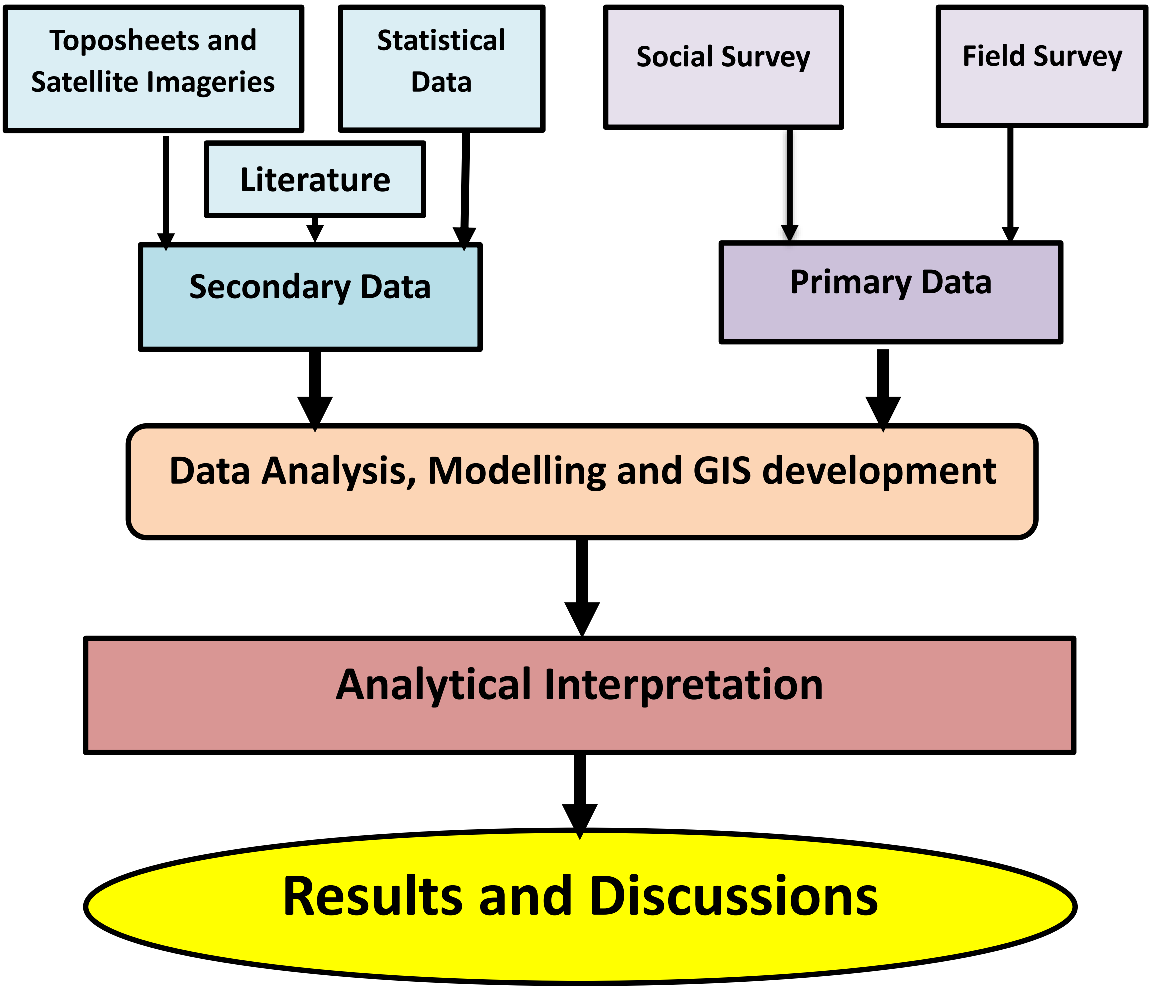


Figure 1.2: Methodology flowchart of the study.

Following a thorough examination of literature on geomorphological hazards in Kohima district, it was determined that a multi-tiered approach would be employed. The core approach would be based on Geospatial analysis, which would be complemented by social survey questionnaires, field surveys, secondary statistical data, secondary meteorological data, and literature support. The widespread availability and distribution of digital geographical resources, together with the growing utilization of geographic information systems (GIS), are generating a growing interest in spatial analysis from those outside the field of spatial sciences (Fischer, 2006). Considering the spatial dimension in research can often lead to distinct and more significant outcomes compared to analysis that disregards it. Geospatial analysis is a study approach that offers distinct approaches and methodologies for examining events that occur in geographical space. Spatial analysis encompasses the process of spatial modelling, which encompasses several models such as location-allocation, spatial interaction, spatial choice and search, spatial optimization, and space-time. These models offer different ways to understanding spatial phenomena. Spatial data analysis primarily involves identifying patterns and investigating the links between these patterns to get insights into the underlying processes that give rise to these patterns. Spatial data analysis focuses on the role of space as a potentially significant factor in explaining socioeconomic systems. It aims to improve our understanding of how space functions and is represented, as well as spatial patterns and processes.

1.4.1. Materials:

i. Literatures
ii. Survey of India toposheets 83 G/13, 83 G/14, 83 K/1, 83 K/2 and 83 K/5 with scale 1:50,000
iii. Google earth imageries
iv. SRTM-DEM (Shuttle Radar Topography Mission- Digital Elevation Model) imageries
v. LANDSAT satellite imageries
vi. Indian Remote Sensing Satellite 1C (IRS-1C) Linear Imaging and Self Scanning Sensor (LISS III) and Panchromatic data (PAN) fusion
vii. ArcGIS software
viii. Statistical data (Earthquakes, Meteorological etc.)
ix. Secondary Census data
x. Field instruments: Stevenson Screen with temperature/humidity recorder, self-recording rain gauge and Pan-evaporation, Pigmy current meter, Abney level, Measuring tape etc.

1.4.2. Methods:

1.4.2.1. Geospatial database development: In order to gather comprehensive data on the geoenvironmental features of the study area, including slope, relief, drainage, geology, geomorphology, soil characteristics, and other relevant factors, we assessed all topographic, hydro-meteorological, and biological elements that impact various geomorphic hazards such as earthquakes, soil erosion, landslides, and flash floods. GIS base maps were created thus using a combination of satellite imageries and topographic sheets in the GIS environment.

1.4.2.2. Models and approaches:

Various concepts and techniques were employed to achieve diverse outcomes. The micro-seismotectonic zonation utilized a combination of the Scalogram Modelling Approach developed by Cruz in 1992 and the Analytical Hierarchy Process introduced by Saaty in 1980.

The Revised Universal Soil Loss Equation (RUSLE) approach, developed by Wischmeier and Smith in 1978, is utilized for soil erosion hazard modelling. The Wischmeier and Smith model, published in 1978, is a highly utilized experimental model for assessing erosion rates. The utilization of geospatial technology-based methodologies, such as DEM, GIS, and remote sensing, allows for the efficient input of spatial data into the RUSLE model. This enables the model to accurately estimate erosion rates in a given study area, whether it be a watershed, river basin, or huge regional landscape.

The Analytical Hierarchy Process (AHP) by Saaty, 1980 was utilized for Landslide hazard zonation and Flash Flood Hazard Zonation. The Analytical Hierarchy Process (AHP), developed by Saaty (1980), is a highly dependable, accurate, and extensively utilized technique for extracting and quantifying subjective judgments in multi-criteria decision-making (MCDM). The integration of this process with digital elevation modelling (DEM) in a GIS environment has further enhanced its credibility (Anand et al., 2022).

The Watershed assessment utilized a combination of field work and GIS technique to conduct hydrometeorological modelling and analyse run-off variations. The pigmy current meter method was employed to quantify the daily stream flow at the outlet of each representative watershed following Rawat, 2011; Rawat, 2013; Rawat, 2014; Rawat and Pant, 2016. The spatial distribution of runoff has been evaluated and charted, taking into account various geophysical factors (such as geology, landforms, topography, slope gradient, drainage features, and soil properties) and ecological factors (including climate, vegetation cover, and land use) using the scalogram modelling approach. The scalogram modelling approach, proposed by Cruz in 1992, entails the integration of an arithmetic operation with numerical weights for the primary components and sub-factors. The purpose of this was to calculate the Runoff Index (RI) for a specific unit area.

Lastly, SWOT analysis (Strength, Weakness, Opportunities and Threats) by Humphrey, 1960 was used to understand and propose various strategies for effective management and mitigation of geomorphological hazards with the help of social survey and literature references.

A combination of all these methods and approaches resulted in a precise and objective outcome of the study of geomorphological hazards in Kohima district which are discussed in detail in the proceeding chapters.

1.5. Review of Literature

The beginning of the modern geomorphological thought and practice is attributed to several scholars towards the end of the eighteenth and the beginning of the nineteenth century. Only recently several geomorphologists have started to think of large-scale short duration events (catastrophic events). The modernization of geomorphology perhaps started with the study of running water in channels and on slopes (fluvial geomorphology). Modern fluvial geomorphology started in the United States. Geomorphology that was practiced in the tropical countries remained old styled until very recently. A number of case studies, based on fieldwork in the low latitude countries changed this concept. The diffusion of process geomorphology to the tropics also brought in the modern theory and methodology (Gupta, 1993).

Excellent examples of the new style of investigation in the tropics and the subtropics include studies by Simonett (1967) on landslides in the earthquake-prone mountains of Papua, New Guinea, Gole and Chitale (1966) on the megafan of the Kosi River and by Coleman (1969) on the Brahmaputra. Starting from the late 1970s, textbooks, based mainly on tropical environment started to appear (Douglas, 1977: Faniran and Jeje, 1983). Anthropogenic alteration of the tropical land has been long and intense. A very strong component of present-day geomorphology in the tropics is the monitoring of such modification of the landscape (Bruijnzeel, 1990).

Geomorphology in India remained old fashioned for a very long time with undue focus on erosional surfaces, denudation chronology, and drainage basin morphometry. Geomorphic studies in sub-continent remained largely qualitative and descriptive with considerable emphasis on models of landscape change (particularly the geographical cycle of erosion).

In the last four decades, geomorphic studies have concentrated on natural and human-induced hazards. Several attempts have been made to investigate erosion and deposition landslides and floods. Also vital to this investigation has been the availability of high resolution Indian remote sensing satellite images and Geographic Information System (GIS). Geomorphology in the tropics, because of its wonderful complexity continuous changes and limited amount of past research investigations provides a wonderful opportunity for new discoveries (Kale and Gupta, 2001). There has always been an applied side to geomorphology. In his textbook first published in 1954, Thornbury included a chapter on applied geomorphology. Currently application of geomorphology in ameliorating damages from natural hazards and in management of environmental hazards are practiced (Kale and Gupta, 2001).

In the past few decades, the discipline of geomorphology has gone through a paradigm shift from geographical geomorphology to geophysical geomorphology (Summerfield, 2005). Ayala (2002) noted that geoscientists specializing in geomorphology and with a background in geography may be the most suitable researchers to study the prevention of natural disasters. This is due to their comprehensive knowledge of both natural processes and their interactions with the human system. Starkel (2004) also advocated that the parallel investigation of environmental elements would support decision-making and the forecast of geomorphic hazards. Slaymaker (1996) categorized geomorphic hazards into three distinct groups: endogenous hazards (such as volcanoes, neo-tectonics, and mountain building), exogenous hazards (such as floods, flash floods, Karst surfaces, mass movements, snow avalanches, and coastal erosion), and hazards related to climate and land use changes (such as desertification, permafrost, degradation, salinization, and water erosion). Goudie (2001) classified hazards into three broad categories as the climatic hazards (dangers of risk associated with atmospheric elements), the geomorphic hazards (largely dependent on structural changes in rocks, mass movements, subsidence or emergence of alternations in relief features or landscape) and the biological hazards (degradation in plant and biodiversity and animal kingdom because of change in habitat and alteration in ecosystem).

Geomorphic hazards occur due to the instability of the surface features of the earth. Pannizza (1987) defines geomorphic hazard as the probability that a certain phenomenon reflecting geomorphological instability will occur in a certain territory in a given period of time. Baker (1994) stated that a little or no understanding exists about the projected future behavior and form of rivers and other natural systems in India in the scenario of uncertainties associated with climate change and the ever-growing impacts of anthropogenic effects. For the purpose of understanding man-nature relationships ‘anthropo-geomorphology' term is given to analyze the human impact on environmental changes (Goudie 1997).

Rawat (2011) pointed out in his book that severity of geomorphic hazards is related more to the disturbances in the geological structure caused by endogenetic processes which are responsible for shaping and reshaping the land surfaces (as active fault zone). The occurrences of calamities or the extremes in weather conditions (exogenetic) are responsible for shaping the pre-existing shapes by altering the valley cross sections, drainage pattern, displaced terraces, emergence of fluvial fans, gully erosion and flash floods. Rawat (2011) also advocated that the mass movement and landslides have been the core subject matter of the studies of geomorphic hazard. Delineation of landslide hazard zones and their mapping are important dimensions for the analysis of landslides. Bilwa, et.al., (2015) remarked that Nagaland is prone to geo-hydrological hazards. The Kohima district is quite active geologically. Geomorphic hazards and related phenomena occur independently or due to human activities. The authors also argued that the poor compressive strength of siltstone makes it inherently weak in the face of humid climates and high rainfall, resulting in significant weathering and erosion. Therefore, slope instability is inherent. Many Geomorphologists have contributed extensively in the study of geomorphological hazards and some of the important ones worth mentioning are Cooke (1984), Oya (2001) and others.

Geomorphology also varies in scale. The range of units studied runs from global region, continental in area to small experimental drainage basin and run-off plots. The study of geomorphological hazards requires several different types of techniques. Fieldwork that involves describing and measuring frequencies, events, type of hazards etc. in the field is classical and an important technique.

A geomorphic hazard can be defined as any change, natural or man-induced, that may affect the geomorphic stability of a landform to the adversity of living things (Chorley et.al., 1984). Geomorphological hazards range from very long-term hazards i.e., crustal instability caused by earth movements leading to mountain building, faulting, folding, warping, subsidence, upliftment; by change in vegetation cover and type and hydrologic regime due to climatic change etc., to short-term hazards i.e., volcanic eruption, earthquakes, floods, landslides, avalanches, riparian decay, changes in discharge, sediment load, soil erosion etc. (Singh, 1998). According to Coates, 1972, geomorphology has diverse application over a large area of natural processes and human activity like applications in the field of environmental studies, especially in the survey of natural hazards, landslides, avalanches, earthquakes, volcanism, land subsidence, flooding and drought. Detailed techniques are given in Dunne and Leopold (1978) but primarily the interest of geomorphologists concerns the determination of the probability of flooding, the effect of such flooding and the extent of flooding (Kale and Gupta, 2001). Geomorphology similarly is used to determine areas prone to mass movements. This information can be used to control landuse and also to take precautions such as vegetating steep slopes providing the subsurface drainage etc. in order to lessen the probability of slope failure (Kale and Gupta, 2001). These areas are usually problematic areas- the steep slopes with a past history of failure and slopes which have been altered by anthropogenic activities. These events, whether caused by natural processes or human factors, are called extreme events which occur very rarely and aggravate natural environmental processes to cause disaster for human society such as sudden tectonic movements leading to earthquake, continued dry conditions leading to prolonged droughts, floods etc., (Singh, 1998). Geomorphic knowledge is useful for identifying, predicting, and evaluating the potential impacts of geomorphic hazards, as well as for managing them. Understanding the behaviour of river systems and their morphological properties, such as channel geometry, channel morphology, and bank morphology, may be beneficial in implementing various flood control techniques to mitigate floods and flash floods. By examining the hillslopes and the kind of rocks they contain, we can determine if the hillslope is stable or unstable and whether there is a risk of landslides occurring. This information would be beneficial for the identification and mapping of unstable hillslopes that should be avoided for human settlements and construction of roads (Singh, 1998).

Geomorphic hazards originate from the endogenetic and exogenetic processes of the earth's landform and can be influenced by human activities to a certain extent. Endogenetic processes are those operating below the earth's surface that result in disasters such as earthquakes, volcanoes and tsunamis and are not appreciably altered by human activities (James et al., 2013). Exogenetic processes, on the other hand, are those processes that operate above the earth's crust, namely weathering, denudation and mass wasting, which are driven by wind and rain in most cases leading to soil erosion, landslides and flash floods and are also greatly affected by land-use and engineering works, i.e., human activities.

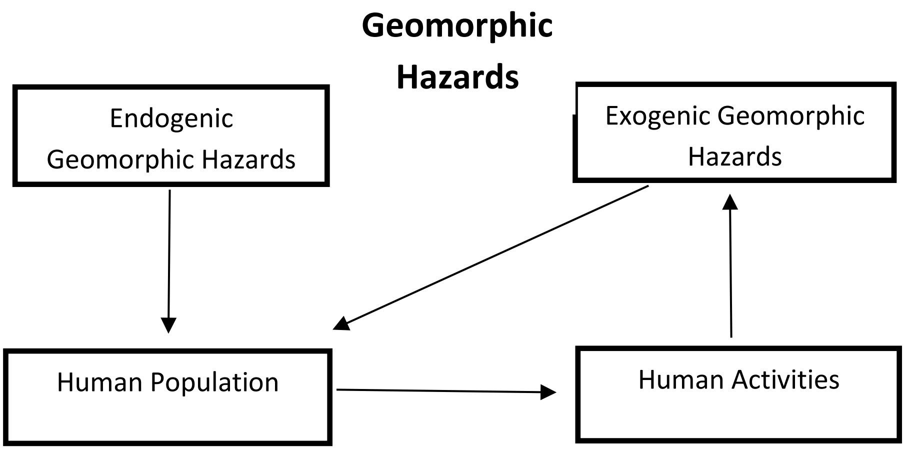


Figure 1.3: System diagram of the interrelationship between Geomorphic hazards and Human society (Source: James et al., 2013).

All geomorphic hazards originating from both processes affects the human population; however, human activities do not alter the endogenic processes. Human interference plays a major role in influencing and affecting the intensity and frequency of exogenic geomorphic hazards. Hazards such as landslides, floods, and soil erosion are always intensified where there are more human interferences. Therefore, while human activities affect the intensity of hazards and disasters, these hazards also affect the population depending on the concentration of settlements in the region. It may be considered that geomorphological and geological hazards do occur as a result of the geomorphological and geological processes and factors acting together at a certain point of time in which though earthquake is purely a result of geological tectonic activities, landslides which may be considered as having a geomorphological origin is by and large affected by the tectonic activities beneath the earth's crust.

India is a country that is faced with multi hazardous events. The Northern Himalayan region experiences earthquakes and landslides, the arid regions experiences drought and wind storms, the coastal region experiences cyclones and tsunamis and the plain regions experiences floods almost every monsoon. Thus, the country is not just a multi-cultured country but also has its fair share of all types of hazards and disasters because of its diverse topography and climate. The Himalayan region of the country which has the highest elevation is a very active region tectonically with its young fold mountain under constant endogenic activity which in place have been affecting the outer landform activities such as weathering, thus paving the way for intensified erosion and landslides and thus earning the status of being geomorphologically and geologically unstable. The North-East Region (NER) is known as the Purvanchal Hills comprising of the Patkai hills, Manipur hills, Barail range, the Mizo hills and the Naga Hills. The NER is inflicted mainly by the hazards of earthquake, landslides and flashfloods owing to the topographic setting and its climatic conditions. Nagaland located in the eastern foothills of India suffers the same hazards the northern hilly region of the Himalayas are exposed to. Both endogenetic and exogenetic process of the geomorphic processes are very active here in the form of tectonic shifts and intense monsoonal rainfall along with its diversity of both plain as well as hilly and rugged topography where the plain regions suffer from flash floods and the hilly regions suffers from landslides in general, while all kinds of hazards are prevalent in every region now considering the intensity of human interference in the environment.

Kohima, the state capital is one such district in Nagaland, that suffers greatly from landslides, flashfloods, soil erosion, mass movement and threats of earthquake of intense magnitude having being classified unde Zone V of seismicity which is the highest seismic zone according to the Ministry of Science & Technology & Earth Science, Govt. of India. The region is geomorphologically captivating yet it suffers the threat of various landform hazards owing to its physiography and climatic conditions. This chapter proceeds with a discussion on the geomorphic hazards prevalent in Kohima district in detail.

The endogenic and exogenic forces causing physical stresses and chemical actions on earth materials and bringing about changes in the configuration of the surface of the earth are known as geomorphic processes. The geomorphic process are all those physical and chemical changes which effect a modification of the earth's surficial form (Thornbury, 1968). It is the process responsible for the formation and alteration of the earth surface. The understanding of the process is therefore crucial for the study of the resultant landforms.

With reference from WD Thornbury's 'Principles of Geomorphology', we can illustrate the geomorphic processes that operates in the environment in the following manner:

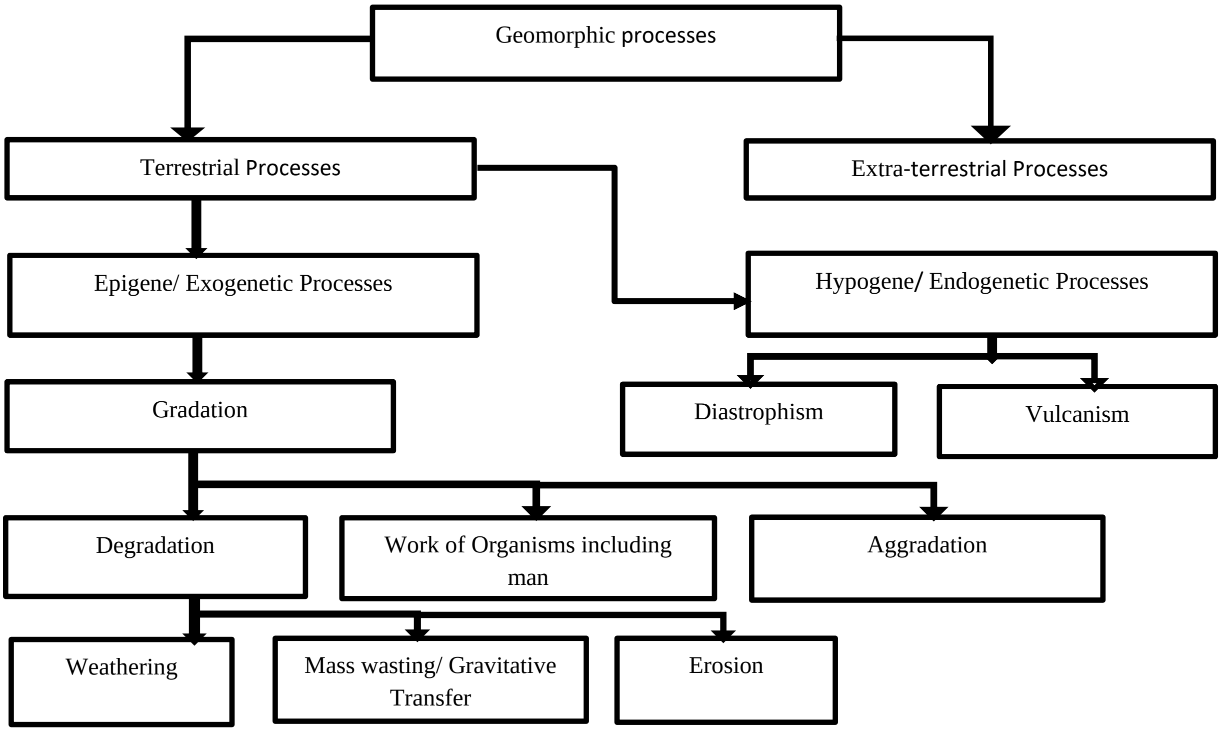


Figure 1.4: Geomorphological Process (Sourced and Modified: W.D. Thornbury, 1997).

As a matter of fact, geomorphic processes include those physical processes which operate on the earth's surface both internally and externally (Singh, 1991). Geomorphic process is classified into terrestrial processes which refers to those processes taking place within the earth while extra-terrestrial processes refer to those taking place outside the earth's atmosphere such as falling of meteorites. However, we are more concerned with those of the terrestrial processes.

For the geomorphological processes to operate, there are several agents which work together in the formation and modification of landforms - river activities, wind activities, glacier activities, and wave activities. These agents in a geomorphic process are activated by 2 major activities, namely- Erosional activities which gives rise to erosional landform features and Depositional activities which gives rise to depositional landform features after undergoing transportation from erosional process.

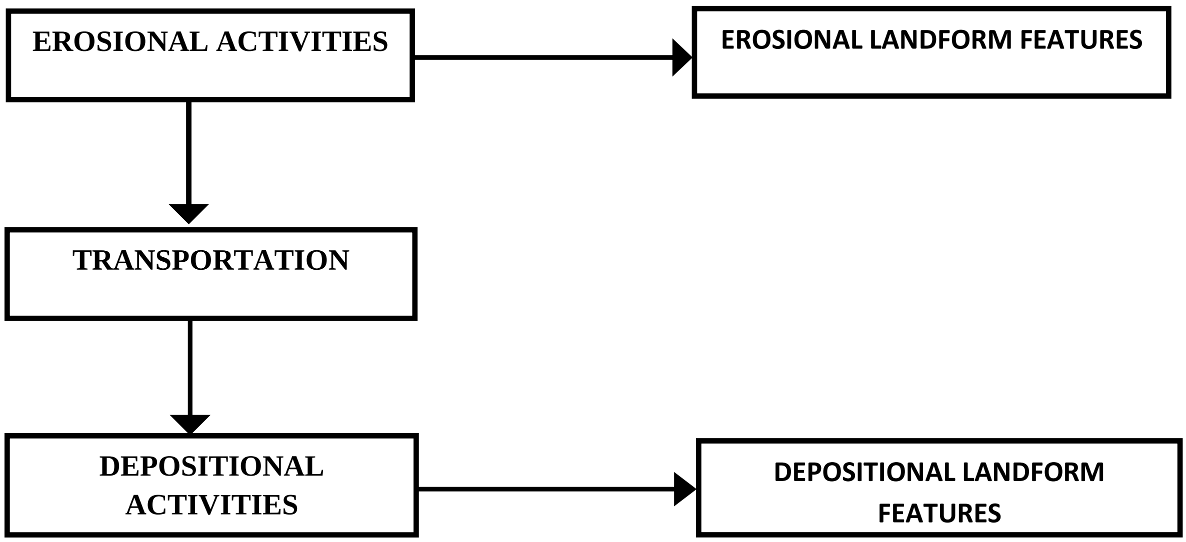


Figure 1.5: Activities of agents of geomorphic processes.

A geomorphic agent or agency is any natural medium which is capable of securing and transporting material (Thornbury, 1968). The geomorphic agents maybe designated to wind, running water, groundwater, waves, tides. These geomorphic agents remove materials from one part of the earth and transports them to another part. Therefore, erosion leads to transportation which further leads to deposition by these geomorphic agents and thus they are also referred to as mobile agents. In all of these activities of geomorphic agents, gravity plays a major role as it directs the force of geomorphic agents and can be thus referred to as a directional force in a geomorphic process. Climate is thus referred to be the sole driving force of all exogenic processes; however, this is considered only on a broader scale. Rawat (2011) has pointed out that on more local scales, it is outweighed by the more rapid structural changes of different, chiefly aclimatic influences. Haigh M.J. et.al., (1988)) has further deduced that the two major aclimatic factors in geomorphology are geographical or geological and they are “epeirovariance”, i.e., the variation in surface form caused by the operations of endogenic processes and “petrovariance”, i.e., the variation of rock types with different structural characteristics and to different capacities to resist erosion. Epeirovariance factor basically refers to the processes that are powered by energy sources deep within the earth where large scale features like ocean basins, ocean ridges, ocean trenches, fold mountains and continents and features associated with faults and folds and volcano owes their origin (Rawat, 2011) and are also referred to as constructional processes (Bloom, 1978). Petrovariance on the other hand dates back to the long-standing principle of geomorphology that the form of a land surface reflects the structure of the underlying material rocks resistance to the denudational processes (Rawat,2011). Therefore, the higher the resistant of the rocks to erosional forces, the landform are considered to be steeper and where the resistance of the rocks are lesser to erosional forces, the landform is supposed to be gentler.

The study area, Kohima district, is situated in the northeastern region of India and is characterized by geological instability. It has continuous rainfall throughout the pre-monsoon and inter-monsoon seasons, which makes it highly susceptible to geomorphological hazards including landslides and flash floods. Annually, the region experiences significant disruption caused by heavy rainfall, which exacerbates the already unstable geological composition of the district. This results in road blockages, property damage, loss of vegetation, and the obstruction of rivers and streams due to landslides. Aside from natural factors such as lithology and climate, the construction of roads has exacerbated the situation by causing more deforestation, excavation of earth materials, and deposition of these materials on land. This has increased the pressure on the land, leading to its sinking.

Natural hazards often fall under the categories of hydro-meteorological and geological phenomena, such as landslides, earthquakes, floods, and tsunamis. These hazards are primarily related to the dynamic character of the earth's surface, making them mostly geomorphological in nature. Geomorphic risks refer to the many dangers posed to human resources due to the instability of the earth's surface characteristics (Gares et.al., 1994). The hazards that arise from landforms are always associated with two types of geomorphic activities: endogenic activity and exogenic activity. Endogenic activities are those landform processing activities which operates from within the earth surface such as seismic and volcanic activities and gives rise to new landforms which also serves as the platform for exogenic activities to operate. Exogenic activities on the other hands relates to those activities such as floods, karst collapse, snow avalanche, channel erosion, sedimentation, mass movement, tsunamis, coastal erosion and those induced by climate and land-use change such as desertification, permafrost, degradation, soil erosion, salinization, floods. (Slaymaker, 1996). Between the 2 geomorphic activities, man can only alter the exogenic activities in terms of escalating its frequency or increasing its intensity such as storms, floods, fire, landslides etc. by human interferences in the form of infrastructure development, climate change, land use and other human-related activities which may have little or more effect on the environment. These hazards are literally considered threats and becomes a disaster when it has a major impact on the society and the infrastructures and produces damage not only at the moment of its occurrence but also on a long-term basis due to their associated consequences (Ayala, 2002). The identification of geomorphic hazard in in reality based on the prediction of landform change (Chorley et. al., 1984). The field of geomorphological hazards encompasses several aspects such as identifying and assessing risks, determining the size of risks, considering different reactions and stakeholders, evaluating the acceptability of risks, avoiding risks, and implementing measures to reduce risks (Singh, 2018).

The primary factor responsible for the most significant geomorphic activity or hazard in Kohima is mostly the result of monsoonal precipitation. In addition to that, Kohima is almost entirely a hilly and undulating terrain It is one of the districts of Nagaland in North-east India which is considered to be one of the most geomorphologically unstable regions in the country and in the world. Kohima district lies on an unstable surficial bedrock. The rocks that make up Kohima consist primarily of Barail and Disang formations, which are composed of splintery shales, sandy shales, sandstones, coarse sand, clay, chalk, slate, gravels, boulder beds, and conglomerates (Thingo, 1994). These rocks are highly permeable, containing fissures, cracks, bedding planes, and joints that allow water to flow easily through them. As a result, the region experiences crustal instability, which is the main cause of its instability. Due to the climatic and geomorphological characteristics of the area, it is very susceptible to many landform hazards like landslides, flash floods, subsidence, erosion, and others. This is mostly due to the increased surface run-off caused by the inadequate internal drainage of the soils and rocks. Due to its ecological instability and fragility, even little disruptions in hilly terrain may greatly amplify the negative effects of natural calamities (Satendra, 2003).

Moreover, as the district experiences population expansion, the instability of the territory grows in terms of intensity, frequency, and area. Research conducted by Thingo (1994) reveals that places with significant human activity tend to have higher levels of land instability. Geomorphic hazards provide a significant risk to human settlements and essential infrastructure, including roads, bridges, and facilities. Nevertheless, it is apparent that the construction of infrastructure often leads to an increase in geomorphic activity (Rainer Bell et al., 2021). Kohima is prone to a variety of geomorphologically induced hazards and catastrophes, including earthquakes, flash floods, sinking, and landslides. Among them, landslides are the most frequent and prevalent danger faced by the district. The occurrence of landslides in Kohima is mostly influenced by rainfall, resulting in a significant number of landslides in and around the district during the pre-monsoon and inter-monsoon seasons. During the monsoon season, Kohima often experiences slumps, which are the downward movement of soil elements across short distances in different areas. While the number of lives killed is infrequent, there is significant damage to towns, infrastructure, roadways, and developmental projects. several sluggish landslides have the propensity to escalate into catastrophic events if left unattended. Consequently, there are several communities located in these places that are at danger of possible calamitous events. The district is mostly covered with soil with a high erosivity factor, accounting for approximately 90% of its area. This characteristic contributes to its susceptibility to slope collapse.

1.6. Scope of the Study

The research on environmental geomorphology aims to study the anthropogenic and natural factors together to explain the spatiotemporal variability and evolutionary characteristics of landscape and landforms. By including both social and physical elements in hazard research, geomorphological risks can be established. The field of geomorphology plays an important role in establishing the risks. Unsustainable developmental processes very often impair ongoing geo-hydrological processes and modify existing landforms which paves the way for natural hazards. It is necessary to acquire a better understanding and appreciation of the geomorphological hazards and a better integration of man and his activities into the mitigation and management of these hazards.

The study will add knowledge to the realm of geomorphological hazards and their mitigation and management in a part of Nagaland. The study will play an increasing role in strengthening applied research using the latest techniques and will highlight the need for such studies for sustainable development. This will provide most of the up-to-date geospatial information which will help to ensure accurate decisions.

The study will also add knowledge on the subject matter in mountain environment geography, applied geomorphology and environmental geomorphology, hazards and disaster mitigation and management. The outcome of the proposed study will be useful for various research communities (for further research) such as geographers, geomorphologists, geologists, hydrologists, meteorologists, ecologists and environmental scientists. The study will propose detailed strategy for mitigation and management of geo-hazards which will be very useful for the policy and decision makers.

This study on geomorphological hazards through a geospatial approach seeks to analyze the combined effects of human activities and natural forces in order to understand the spatial and temporal variations and evolutionary traits of landscapes and landforms. Geomorphological hazards can be established by including both social and physical aspects in hazard studies. Geomorphology is crucial in determining the hazards involved. Unsustainable developmental activities frequently disrupt ongoing geo-hydrological processes and alter existing landforms, leading to the occurrence of natural disasters. It is imperative to have a more comprehensive knowledge and recognition of the geomorphological dangers, as well as to effectively include human activities into the efforts to reduce and control these hazards. The study will contribute to the understanding of geomorphological risks and their mitigation and management in a specific area in Nagaland. The study will have a growing impact on enhancing applied research by utilizing cutting-edge approaches and emphasizing the importance of such studies for sustainable development. This will offer a comprehensive range of current geographical data, facilitating precise decision-making. The study will contribute to the existing knowledge in the fields of mountain environment geography, applied geomorphology, environmental geomorphology, hazards, and disaster mitigation and management. The findings of the proposed study will be valuable for several research communities, including geographers, geomorphologists, geologists, hydrologists, meteorologists, ecologists, and environmental scientists, who may utilize them for future research purposes. The research will present a comprehensive plan for reducing and controlling geo-hazards, which will be highly valuable for policymakers and decision-makers.

References

Ayala, A.I. (2002). Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47 (2): 107–124.

Baker, V.R. (1994). Geomorphological understanding of floods. Geomorphology 10 (1-4): pp. 139–156.

Bell, R., Fort, M., Götz, J., Bernsteiner, H., Andermann, C., Etzlstorfer, J., Posch, E., Gurung, N., & Gurung, S. (2021). Major geomorphic events and natural hazards during monsoonal precipitation 2018 in the Kali Gandaki Valley, Nepal Himalaya. Geomorphology, 372, 107451. https://doi.org/10.1016/j.geomorph.2020.107451

Bhattacharjee, C.C., Rahman, S., Sarmah, R.N., & Thong, G.T., (1998). Landslides and road instability along NH 39, between Kohima and Chumukedima, Nagaland. Proc. Intl. Conf. Dis. Man., Guwahati.

Bilwa, L.M., Yanthan, M.A., Madesh, P. & Hutti, B. (2015). Identification of Potential Landslide Hazard Zonation Mapping using Geoinformatics for Kohima Region, Nagaland, India International Journal of Innovative Science, Engineering & Technology, (IJISET) Vol. 2 (11).

Bloom, A. L. 1978: Geomorphology. A systematic analysis of late Cenozoic land forms. Englewood Cliffs, New Jersey: Prentice-Hall. xvii + 510 pp. £15.95: Ritter, D. F. 1978: Process geomorphology. Dubuque, Iowa: Wm C. Brown. xii + 603pp.

Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? Agriculture, Ecosystems & Environment, 104(1), 185–228. https://doi.org/10.1016/j.agee.2004.01.015.

Chorley, R.J., Schumm, S.A., and Sugden, D.E., (1985). Geomorphology, Methuen and Co.Ltd. London, New York.

Coates, D.R. (1972). Environmental Geomorphology and landscape conservation, Vol. 1, Prior to 1900, benchmark paper in Geology, Dowden, Hutchinson and Ross, Stroudsbury.

Coleman, J.M. (1969). Brahmaputra River : Channel processes and sedimentation. Sedimentary Geology, 3, 129–239.

Cooke, R.U. (1984). Geomorphological Hazards in Los Angeles: A Study of Slope and Sediment Problems in a Metropolitan city. The London Research Series in Geography. Vol. 7. xv+206. George Allen and Unwin.

Das, T., Kothari, D. V., & Ojha, D. C. (1996). Bibliography on Desertification Soil Conservation and Environment.

Demek, J., Kalvoda, J., Kirchner, K. and Vilimek, V. (2006). Geomorphological Aspects of Natural Hazards and Risks in Czech Republic.

District Census Handbook Kohima. (2011). Primary Census Abstract, Government of India, Nagaland.

Douglas, I. (1993). The Tropics: Environments And Human Impacts Understood and Reinterpreted. Singapore Journal of Tropical Geography, 14(2), 103–122. https://doi.org/10.1111/j.1467-9493.1993.tb00044.x

Downs, P.W. & Booth, D.B. (2011). Geomorphology in Environmental Management; The Sage Handbook of Geomorphology: 81–101.

Dunne, T. and Leopold, L.B. (1978). Water in Environmental Planning. Freeman, New York, 818 p.

Enayat, A. (1985). Weakly compact cardinals in models of set theory. The Journal of Symbolic Logic, 50(2), 476–486.

Faniran, A. and Jeje, L.K. (1983). Humid Tropical Geomorphology. Longman Groups Ltd., Ibadan.

Fischer, Manfred. (2006). Spatial Analysis in Geography. 10.1007/3-540-35730-0_2.

Gares, P.A., Sherman, D.J. & Nordstrom, K.F. (1994). Geomorphology and natural hazards. Geomorphology 10: pp. 1–18.

Gole, C.V., & Chitale, S.V. (1966). Inland Delta Building Activity of Kosi River. Journal of Hydraulic Engineering, 92, 111-126.

Goudie, A. (1997). The Human Impact Reader- Readings and Case Studies, Blackwell Publishers, Oxford.

Goudie, A. (2001). The nature of environment (fourth edition). Blackwell Publishers Ltd. Oxford (UK).

Gregory, K. J., & Lewin, J. (2014). The Basics of Geomorphology: Key Concepts. SAGE Publications, Ltd. https://doi.org/10.4135/9781473909984

Gupta, A. (1993). The changing geomorphology of the humid tropics. Geomorphology, 7(1–3), pp. 165–186. https://doi.org/10.1016/0169-555X(93)90016-U

Haigh MJ, Rawat JS, Bisht HS (1988). Hydrological impact of deforestation in the central Himalaya. Proceedings of the Strbské Pleso Workshop, Czechoslovakia.

Hibbeler, L. A. (2007). The role of Geomorphology in Natural Hazards Management. San Francisco State University.

Indian Journal of Geomorphology (2010) Volume 15 (1 and 2). Indian Institute of Geomorphologists.

James, L, A., Harden, J, J., Clague. 2013. Geomorphology of Human Disturbances, Climate Change, and Hazards. Academic Press. Pages 1-13.

Journal of Indian Geomorphology (2013) Vol. 2. Indian Institute of Geomorphologists.

Kale, V.S. and Gupta, A. (2001): Introduction to Geomorphology. Orient Longman Limited. P. 256.

Kalvoda, J. (1996). The geodynamics of landforms hazard processes. Acta Univ. Carol., Geographica 31, 2, 7–32.

Kalwar, S.C., Sharma, M.L., Gurjar, R.D., Khandelwal M.K., and Wadhawan, S.K (2005). Geomorphology and Environmental Sustainability. Concept Publishing Company, New Delhi.

Kapur, A. (2009). On Disaster in India. Cambridge University Press India, Pvt. Ltd. New Delhi.

Katupotha, K. N. J. (2004). Geography Subject.

Khatsii, P. (2004). Urban multi- hazard risk analysis using GIS and Remote Sensing; A case study of landslide, earthquake and fire hazard in a part of Kohima town, India. ITC, The Netherlands and Indian Institue of Remote Sensing, Dehradun.

Nag, Pritvish, Kumra, V.K. and Singh, Jagadish (1997). Geography and Environment; Volume one, National Issues. Concept Publishing Company, New Delhi.National Disaster Risk Reduction Portal (Nagaland).

Oya, M. (2001). Applied Geomorphology for Mitigation of Natural Hazards (Vol. 15). Springer Netherlands. https://doi.org/10.1007/978-94-010-0961-4.

Pannizza, M. (1987). Geomorphological hazard assessment and the analysis of geomorphological risk. In V.Gardiner (ed.) International Geomorphology 1986, pp. 225–229. Part I. New York: Wiley.

Pirazizy, A.A (1992): Environmental Geography and Natural Hazards; Concept's International Series in Environment. Concept Publishing Company, Delhi.

Rawat, M.S. (2011). Environmental Geomorphology and Watershed Management. Concept Publishing Company, New Delhi, pp. 1-286

Rawat, M. S. (2017). Environmental management in the headwater catchments of Kiliki river, Nagaland, North East India. In Ecosystem Services of Headwater Catchments, Josef Kreceket. al., (eds). Springer (via Capital Book Pvt. Ltd, New Delhi), pp. 130–141.

Rawat, M. S., Rawat, J. S. and Haigh, M. J. (1992). Sediment discharge from a Himalayan pine forested headwater. In Environmental Regeneration in Headwaters. Josef Krecek and M. J. Haigh (eds.), Institute of Applied Ecology, Agricultural University of Prague, Czech Republic, 182-187.

Rosenfeld, C. L. (1994). The geomorphological dimensions of natural disasters. Geomorphology, 10(1–4), 27–36. https://doi.org/10.1016/0169-555X(94)90006-X

Satendra (2003): Disaster Management in the Hills. Concept Publishing Company, New Delhi.

Saxena, H. M. (1999). Environmental Geography (Vol. viii). Jaipur Rawat Publications c1999.

Sharma, H.S (1991). Indian Geomorphology; Selected papers from the 2nd Conference of the Indian Institute of Geomorphologists on Environmental Geomorphology. Concept Publishing Company, New Delhi.

Simonett, D. S. (1967). Landslide distribution and earthquakes in the Bewani and Torricelli Mountains, New Guinea. Landform Studies from Australia and New Guinea (Ed by J. N. Jennings & J. A. Mabbutt), pp. 64-84. Cambridge University Press, Cambridge

Singh, S. (1991). Ecology. Prayag Pustak Bhawan

Singh, S. (1998). Geomorphology. Prayag Pustak Bhawan, 1998.

Singh, S. (2007). Geomorphology (Vol. iv). Prayag Pustak Bhawan, 2007.

Slaymaker, O. (1996). Geomorphic Hazards. Wiley Chichester, pp. 1-7.

Starkel, H. (2004). Temporal clustering of extreme rainfall events in relief transformation. Journal Geological Society of India, pp. 64, 517–523.

Summerfield, M.A. (2005). The changing landscape of geomorphology. Earth Surface Processes, Landforms, 30, 729-781.

Thingo, V. (1994). Terrain evaluation of Kohima District, Nagaland, with special reference to Geomorphology. PhD Thesis. Gauhati University.

Thornbury, W. D. (1954). Principles of Geomorphology. Soil Science, 78(2), 157. https://doi.org/10.1097/00010694-195408000-00023.

Thornbury, W. D., (1968). Geomorphology, Wiley Publishers.

Valdiya, K.S (2004). Geology, Environment and Society. University Press (India) Private Limited.

Verstappen, H. (1983). Applied Geomorphology: Geomorphological Surveys for Environmental Development. Elsevier, New York.

Yhoshii, K. and Krishnaiah, Y.V.: Landslide Hazard Zonation Map of Kohima, Nagaland using GIS-Based Approach. Department of Geography, Nagaland University, Lumami India.

GEOGRAPHICAL OVERVIEW

In order to estimate the risk associated with geomorphic hazards such as erosion, mass movement, landslides, slope failures, earthquakes, and flash floods, it is essential to conduct a thorough geographical analysis of the specific area of concern and its surrounding region. A geographical study examines the vulnerability of a region to geomorphic hazards by analysing its geophysical characteristics (including tectonics, geological background, geomorphology, relief pattern, slope gradient, drainage system, climate, soil, vegetation, etc.). It also considers the vulnerability of the region to geomorphic disaster risk based on its anthropogenic characteristics, such as land use pattern, cultural profile, demographic setup, caste composition, occupational structure, migration, literacy, and awareness of environmental issues like geomorphic hazards, hydrological hazards, human-induced hazards, climate change, water and food conservation, etc. It is important to note that geospatial technology (GIS and Remote Sensing) has been used to study the many geophysical and anthropogenic elements contributing to geomorphic hazards in the Kohima district of Nagaland, located in Northeast India. These factors have been categorized into two main sections: physical geography and human geography.

From a physiographic perspective, Nagaland may be categorized into three mountain ranges that extend in a northeast-southwest direction.: i) Eastern Mountain Ranges or High Hill Ranges in the east, ii) Middle Hilly Ranges or Medium High Hill Ranges in the intermediate zone, and iii) Western Low Ranges. The state of Nagaland, located in the North-East Hill (NEH) region, has an area of 16579 km^2. It has an elevation range of 194 m to 3048 m above mean sea level. The climate of Nagaland varies from sub-temperate to sub-tropical. The topography, characterized by hills, harsh terrain, and high mountain ranges, significantly influences the distribution of population and the cultural landscape of Nagaland (Rawat, 2011). The intricate geological formations and the tectonic forces that uplifted these mountain ranges, together with the processes of weathering, erosion, mass movement, seismic activity, and other factors, significantly impact and alter the natural ecology of the area. Nagaland is located in zone V of the seismic map, which is the greatest risk zone for earthquakes. In this zone, the magnitude of earthquakes can surpass 8, making the state particularly vulnerable to seismic activity. The regions next to geological faults, which experience frequent tectonic movements, are very susceptible to slope failure, landslides, and soil erosion. Human meddling has disrupted the natural equilibrium. The risks of soil erosion and mass movement have reached a concerning level in Nagaland.

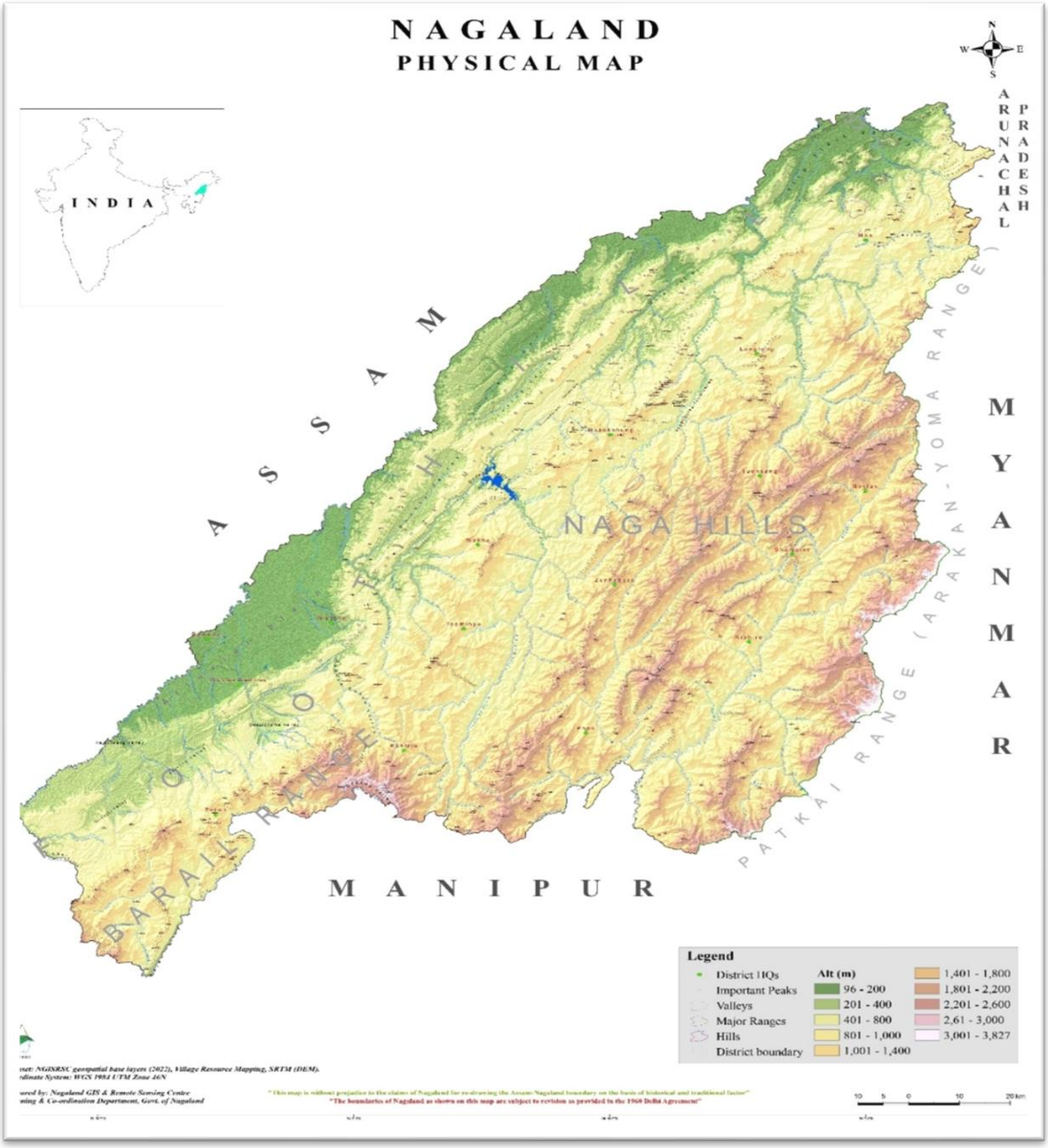


Figure 2.1: Physical map of Nagaland, India (Source: Nagaland GIS and Remote Sensing Centre, Kohima, NGISRSC).

2.1. Physical Geography of the Study Area

Physical Geography is a field of study that examines and connects the significant components of the natural world that humans inhabit (Strahler & Strahler, 1978). The field of physical geography offers insights into the many patterns and phenomena occurring in the spatial environment. It gives a comprehensive understanding of the environment's impact on humans and vice versa. The environmental conditions of human habitat are determined by the physical components of land, air, and water. It plays a crucial role in sustaining life within the biosphere (Singh, 2009). Due to natural processes, the environment has always been susceptible to changes. However, these changes have become more severe and harmful to both humans and the environment. This is primarily due to the increase in population and the lack of proper scientific support in developmental activities. Understanding the physical features of the environment and how they work is crucial, not just in theory but also in practice, to protect the environment for the benefit of all living beings. The following content provides a description of the essential aspects of the physical geography of the Kohima district, including the spatial and attribute database of the related GIS maps.

2.1.1 Physiography

Physiography is the result of the structure, processes, and stages of evolution of landforms. The physiography of a location has many impacts on the ecosystem. Kohima is mostly located within the Middle Mountain range and partially inside the Barail Mountain range system. The Japfii mountain, with an elevation of 3014 meters above mean sea level, is the tallest peak in the area. The district's average elevation is around 1261 m above mean sea level, and it consists of an uneven plateau with high hills and peaks (District Census Handbook Kohima, 2011). The physiographic units of Kohima district may be classified based on their elevation, arranged in ascending order:

The Undulating zone*:* This zone has a varying altitude of 204 m to 829 m above sea level and covers the northwestern and somewhat northeastern parts of the district. The area is defined by a gradual incline that ranges from 0^o to 15^o and is marked by significant rivers such the Dzudza ru, Sidzu ru, Dzu ru, and Chathe ru. The Zubza valley is also included within this zone. It encompasses around 20% of the total land area. The region consists primarily of large sandstones, with smaller amounts of clays and shales in the lower section. In contrast, the upper areas are characterized by loose masses of boulders and pebbles mixed with clay and soft sand. These geological formations are from the Mio-Pliocene era, as described by Thingo in 1994.

The Piedmont zone: This zone encompasses an elevation range of 829 m to 1174 m above mean sea level. It mostly consists of gradual slopes that extend from the base of mountains to a level expanse of land. This zone is the largest and encompasses around 60% of the district. It notably traverses the middle section of the territory and gradually narrows towards both the eastern and western parts of the district. This zone is characterized by a high population density, with the Kohima town being the most densely populated area within it. The gradient of the area varies from 8º to 25º.

The Dissected Highland Plateau*:* This zone is located only in the southern half of the district and has an elevation that ranges from 1174 m to 2166 m above mean sea level. The gradient in this area is rather steep, varying from 25º to 35º. The Dzuleke valley is located inside this zone. They comprise around 10% of the whole area. The rocks are from the Barail formation. The streams in this area exhibit dendritic patterns, which suggest a consistent and uniform structure and geology.

The Structural Hills and Mountains*:* This zone has the greatest altitude, ranging from 2166 m to 2953 m above mean sea level, and covers 5% of the entire area. They traverse the southernmost region of the district. This area features the most noticeable hills, characterized by a slope above 35º. Japfu is the second highest peak in the region. This zone is traversed by the renowned Dzukou valley, which is distinguished by its profound canyons and V-shaped valleys.

2.1.1.1 Spatial variability of relief and slope gradient: The Digital Elevation Model (DEM) of the region accurately represents the varied topography and slope features of the region. The relief ranges from 204m to 2953m above mean sea level and has been classified into five categories based on elevation, from lowest to highest (Figure 2.2). Within the area, the slope gradient ranges from <10° to >60° across several relief categories (Figure 2.3). The difference in slope gradient has been classified into five groups: gentle (less than 10°), moderate (11°-25°), high (26°-35°), steep (36º - 45º) and very steep (more than 46°). The lower elevations (204-829 m) encompass many locations, such as the master river valleys, the alluvial plain region of Dimapur, and the over thrust zone of the 'belt of schuppen'. These areas mostly consist of shale and sandstone and are characterized by mild slopes (<10°). They make up around 16.8% of the region. The moderate slope category (11°-25°) encompasses the mid-slope parts of the hill zone, which have an elevation ranging from 829 to 1174m. These areas occupy around 25% of the region's total area. The upward slope altitude ranging from 1174 to 1605 meters is referred to as the high slope zone, with inclines between 26º and 35º. This zone encompasses 23% of the territory. The hilltop area in the region is characterized by scarped valleys with vertical sides, which are governed by tectonic activity.

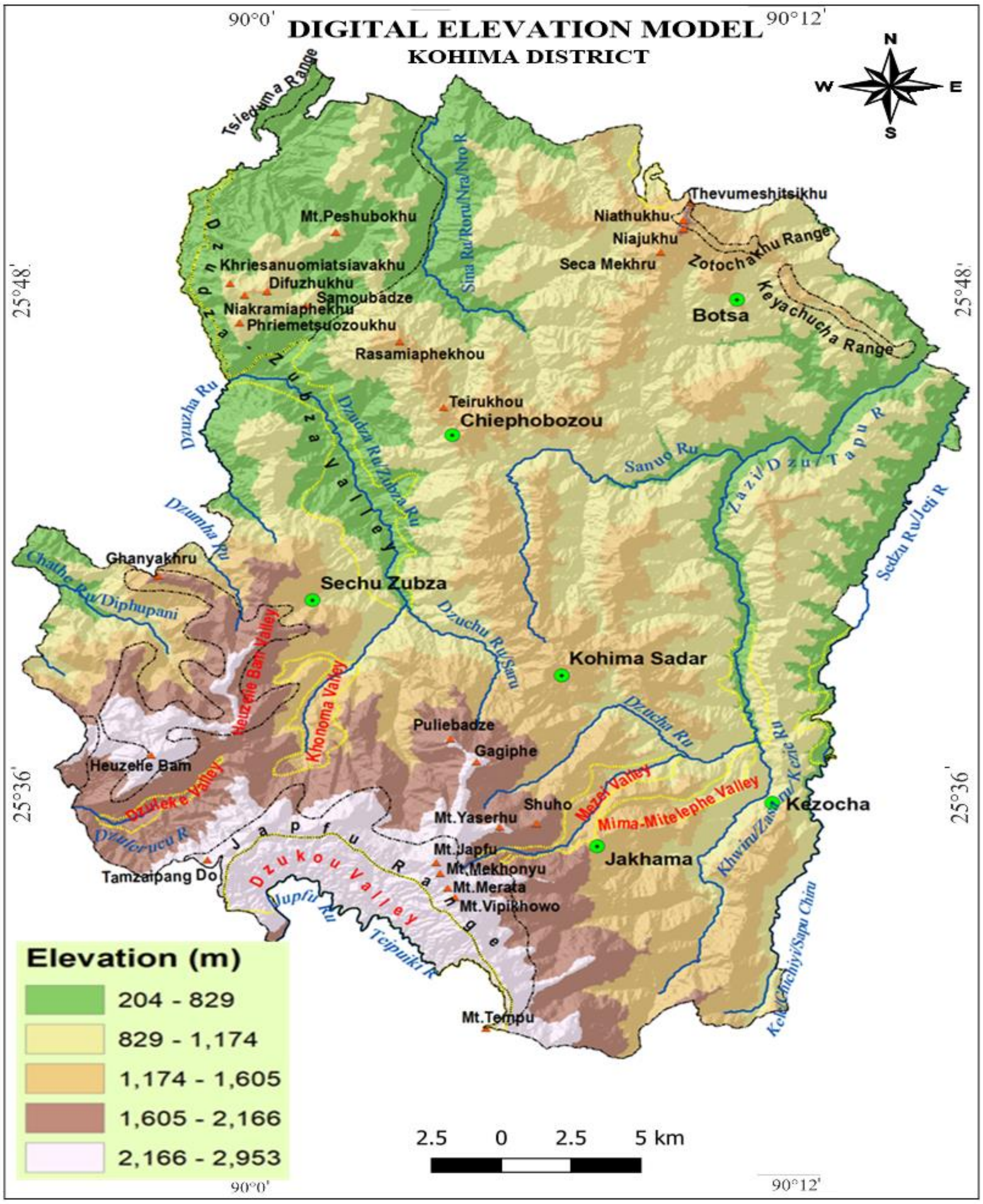


Figure 2.2: Physical map of Kohima district, Nagaland (Digital Elevation Model: DEM).

This area has a steep slope gradient, between 36º-45º, and it encompasses 29% of the territory. Very steep slope with inclination exceeding 46º falls under the elevation ranging between 2166- 2953 meters above mean sea level and accounts for 6.2% of the area. Landslides are also common in this area. The slope map indicates that the western and southern regions of the district have steep slopes, while the central area and narrow extensions to the west and east have more gradual slopes, allowing for a dense population.

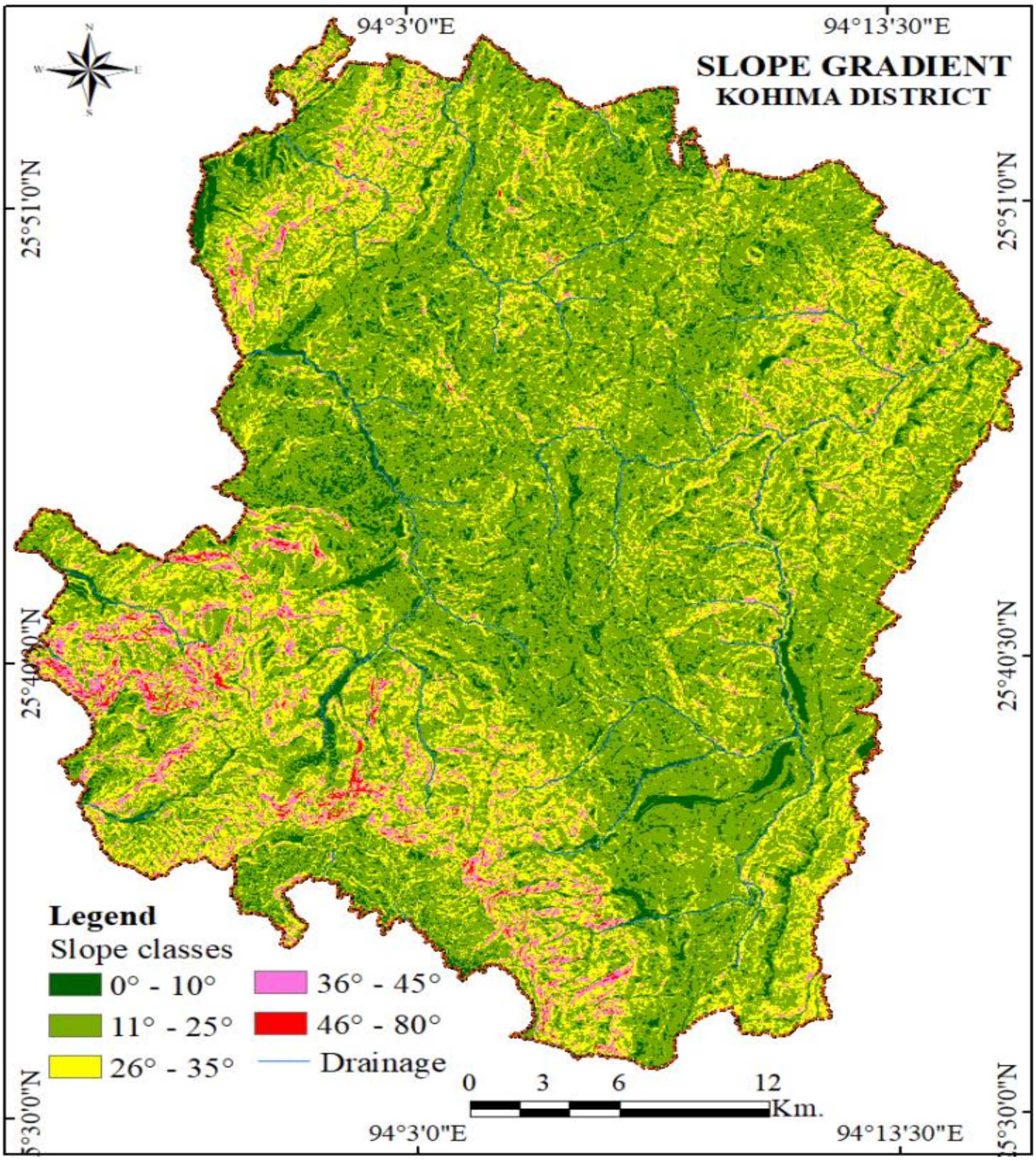


Figure 2.3: Spatial variability of slope gradient of Kohima district, Nagaland

2.1.1.2 Slope aspects: An aspect map is a tool that uses colour to represent the direction and angle of a slope. Figure 2.4 illustrates the geographical arrangement of slope aspects in the Kohima region. It indicates that the central-southernmost point in the district faces south with an angle ranging from 157.5^{o} to 202.5^{o}. This information provides insight into the direction and steepness of the terrain. Aspect is a measurement that indicates the clockwise direction, starting from 0^{o} and ending at 360^{o}. When the number is -1, it signifies that the terrain is flat.

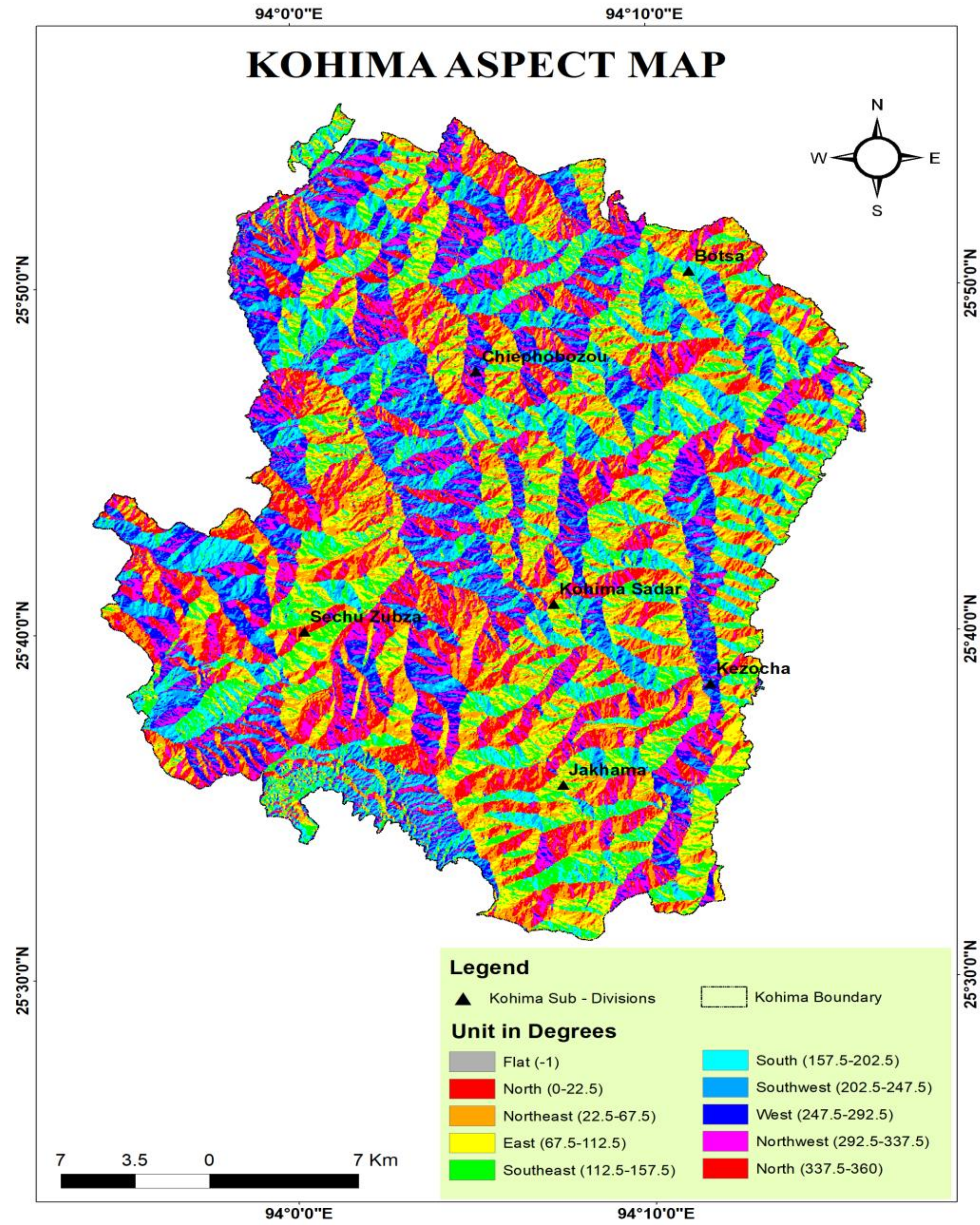


Figure 2.4: Slope aspects orientation of Kohima district, Nagaland

2.1.1.3. Surface roughness: Surface roughness was assessed using hill shadow mapping, as shown in Figure 2.5. A hillshade map is a three-dimensional depiction of the terrain surface, which considers the sun's relative location. It provides a graphical representation of the vertical and horizontal aspects of the land. Regarding Kohima, it can be inferred that the landscape in the entire district is characterized by steep and uneven topography. The hills in the middle portion of the district have lesser elevations compared to the southern and northwestern parts, which exhibit very high raised topography. This observation supports the prior physical interpretations of the area as shown in figure 2.5.

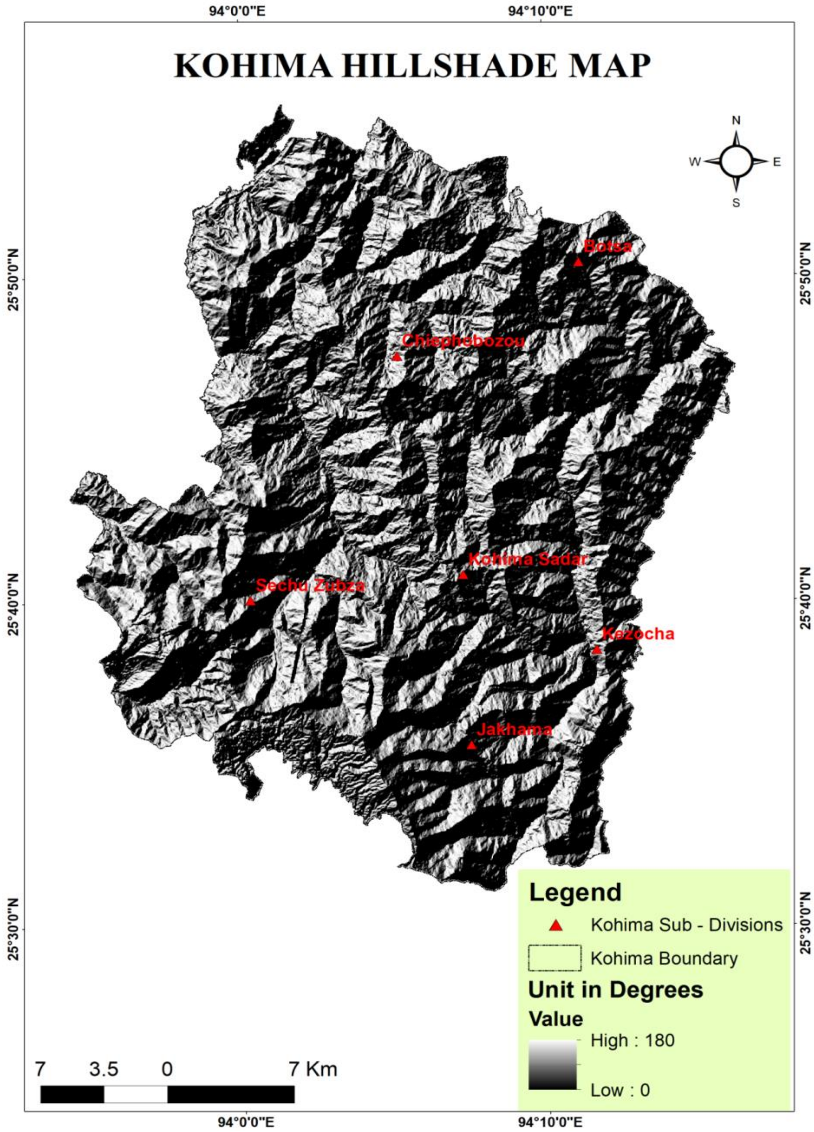


Figure 2.5: Surface roughness and hillshade map of Kohima district, Nagaland

2.1.2. Geomorphology

Geomorphology is a field of study that focuses on the analysis and understanding of landforms, their associated landscapes, and the many processes that shape and modify them on the Earth's surface. Geomorphology is the study of the physical features and processes that shape the Earth's surface. According to William D. Thornbury, geomorphology is commonly regarded as the study of landforms, although it may also encompass underwater formations. Some scientists in each generation opt to specialize on the analysis, methodical description, and comprehension of landscapes and the mechanisms that alter them. The individuals mentioned are experts in the field of geomorphology (Bloom, 2012). Geomorphology is an interdisciplinary field that combines elements of geology and geography. Its primary focus is the investigation of the formation and evolution of landforms seen on the Earth's surface. The fundamental components in the field of Geomorphology are the structure, process, and stage of a landform. Landforms may be formed by constructional processes such as volcanic and tectonic activity. On the other hand, landforms can also be shaped through destructional or erosional processes caused by air weathering and erosion. According to Bloom (2012), "a missing rock is as significant as the rock mass that remains" in geomorphology when it comes to identifying and comprehending the landform. Landforms may be broadly classified into two categories: initial landforms and sequential landforms. First landforms are formed immediately as a result of volcanic and tectonic activity, while sequential landforms are formed by the process of denudation operating upon first landforms after they have been lifted to a higher position. Geomorphology primarily focuses on the study of the natural processes of volcanic and tectonic activity, as well as denudational processes, which shape the land formations we see today. However, in addition to these natural processes, humans have emerged as a powerful force in shaping the Earth's surface and the processes that affect it, thanks to their ability to alter it. The study of anthropogenic geomorphology has emerged as a result of the significant influence of human activities on the constantly evolving environmental landscape. The hazards and disasters we encounter are mostly caused by geomorphological processes. However, as time passes and the population grows, along with increased development, the study of a region's geomorphology cannot be conducted without considering the influence of human activities. A significant proportion of Nagaland is comprised of semi-consolidated rock formations characterized by mountainous and rough terrains that have experienced significant tectonic forces and extensive structural deformations. The hills of Nagaland are geologically connected to the Burmese arc and are part of the Himalayan range in the north (Figure 2.6).

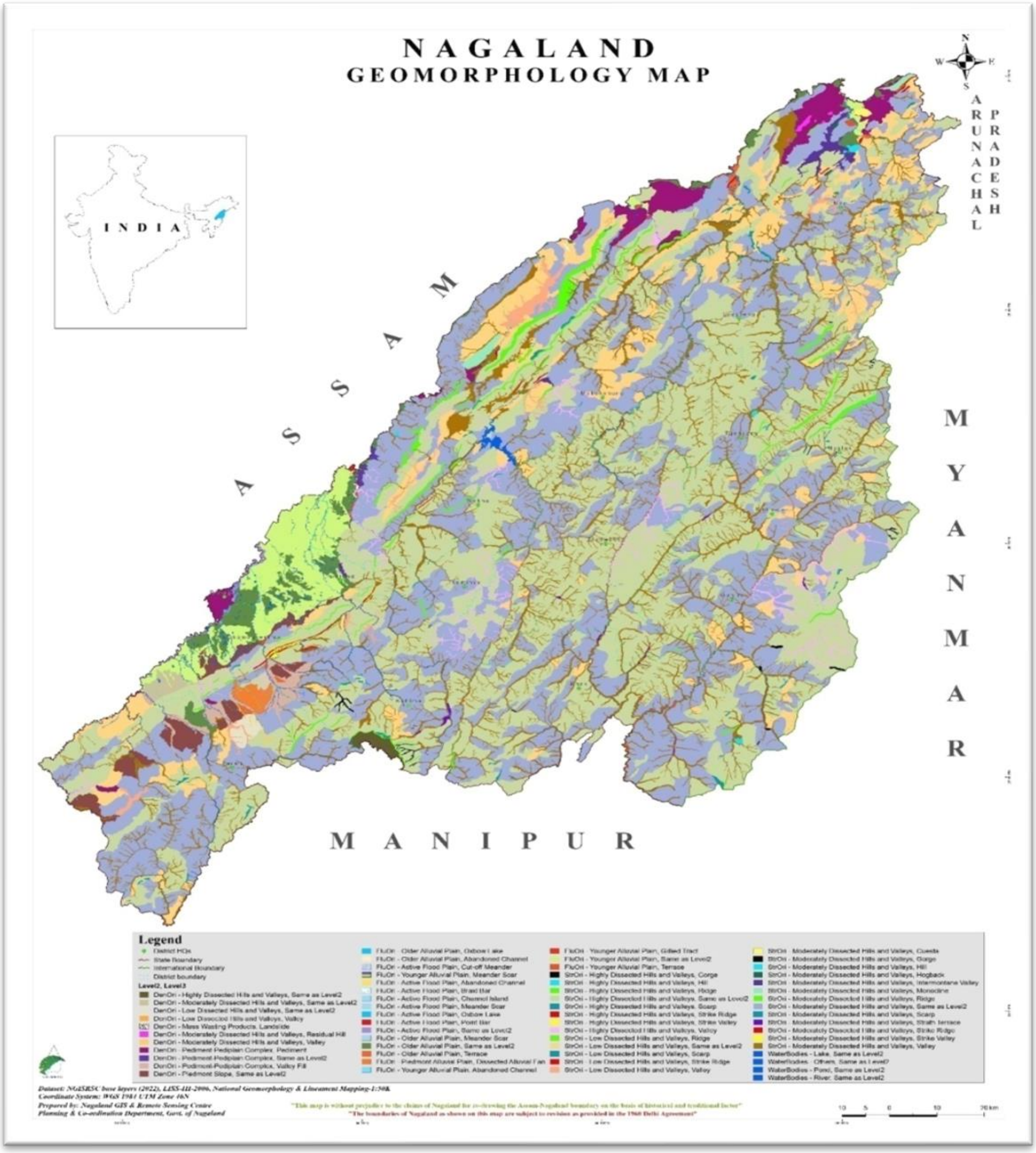


Figure 2.6: Geomorphological map of Nagaland (Source: NGISRSC)

Kohima district in Nagaland state consists of low denuded hills from the Disang group, which are topped by steeper ridges of Barail sandstones. The district has a mean height of 1444m above sea level and may be broadly split into three geomorphic zones (Figure 2.7):

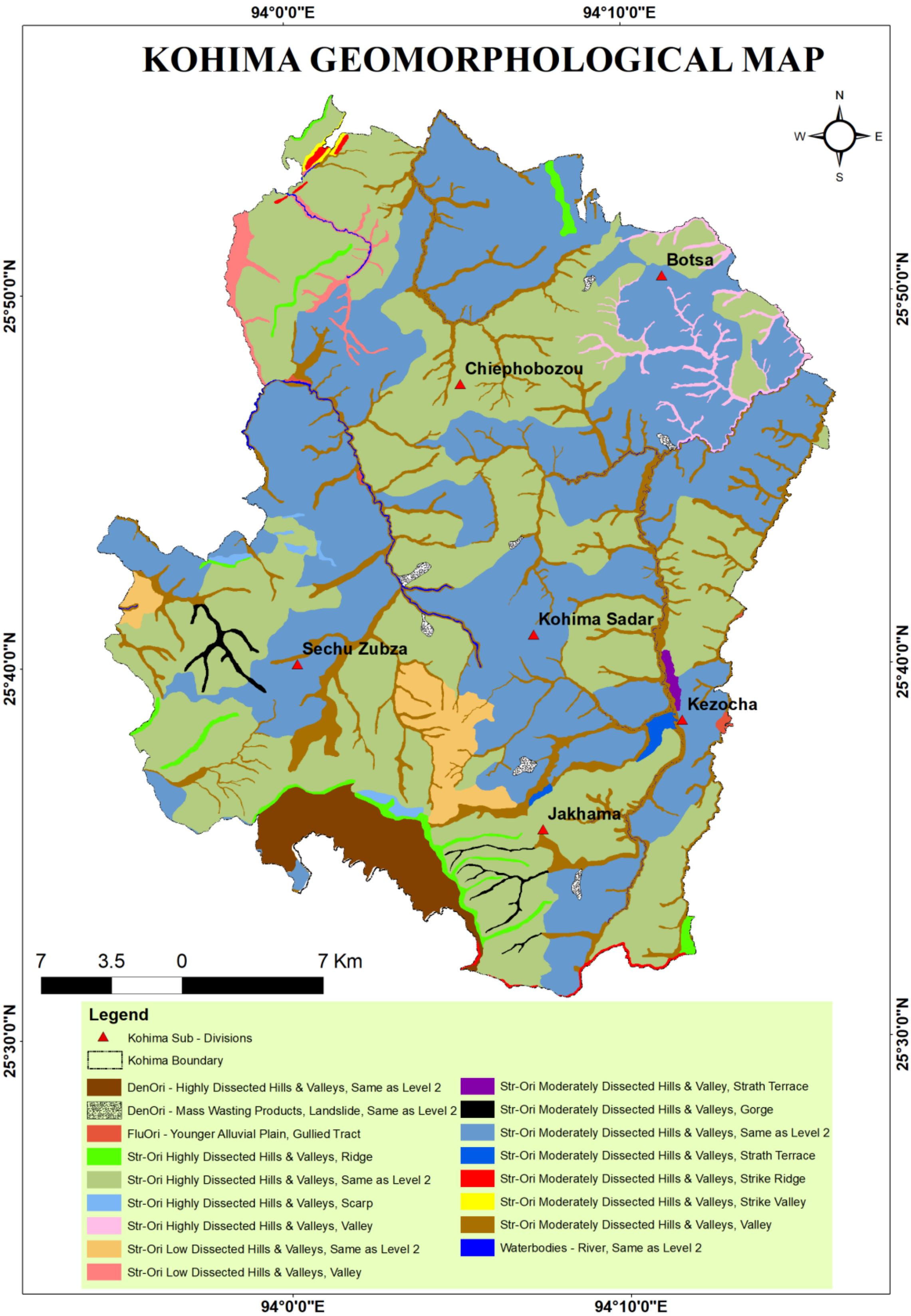


Figure 2.7: Geomorphological map of Kohima district, Nagaland.

2.1.2.1. Highly dissected hills and valleys: The terrain in this area has an average slope above 33° and is distinguished by structural hills and mountains with a dissected highland plateau. It is especially noticeable in the southern section of the district. This area is home to the highest peak of Japfu and also encompasses the Dzukuo mountains. The region is characterized by extensively carved v-shaped valleys, with deep gorges formed by steep slopes and a high surface run-off. The erosivity factor is persistent due to the region's frequent occurrence of high-intensity rainfall. The vegetation in this area is abundant and the woodlands are extensive, with only a few villages present. The height of the area varies between 1500-3048m above sea level. The lithology consists mostly of barail origin, characterized by deep bedded, consistently hard, ferogenous sandstones. It encompasses portions of Zubza and Jakhama circles within the Kohima district.

2.1.2.2. Moderately dissected hills and valleys: Approximately half of the area is made up of moderately dissected hills and valleys, which are characterized by gently rolling slopes ranging from 14° to 33°. It is the largest region and includes significant portions of Chiephobozou, Botsa, Kohima sadar, and Kezocha circle of the district. The population density in this particular area of the relief is the greatest due to its gradual and rolling terrain, which is situated at an elevation ranging from 300 to 1500 meters. The area consists primarily of rocks derived from the Disang and Barail formations.

2.1.2.3. Low dissected hills and valleys: This area comprises a mere 2% of the district and is distinguished by flat, fertile plains in certain areas of Zubza, Tsogin, and Botsa circles within the district. The western portion of the district is predominantly characterized by this geomorphological category, but a tiny and sparsely populated area in the eastern section also comes within its scope. The slope of the area varies from 0 to 14º, while the height ranges from 100 to 140 meters. The rock formations consist of sandstone, siltstone, and claystone.

2.1.3. Geology

The Assam-Arakan Orogenic province in Northeast India is composed of three parts: the Naga Hills, Chin Hills, and Arakan Yoma portions (Srivastava et.al, 2013). The Naga hills, with an elevation of approximately 3840 m above mean sea level, are located near the boundary between India and Myanmar. Nagaland is a region that is part of the mobile morphotectonic unit of the Indian Plate, which experienced a collision with the Burmese Plate (Bhattacharjee, 1991). Nagaland may be categorized into four primary structural groups: the Belt of Schuppen, Patkai Synclinorium, Kohima Synclinorium, and the Ophiolite

Complex. These units all exhibit a northeast-southwest orientation, as seen in Figure 2.8 and Table 2.1.

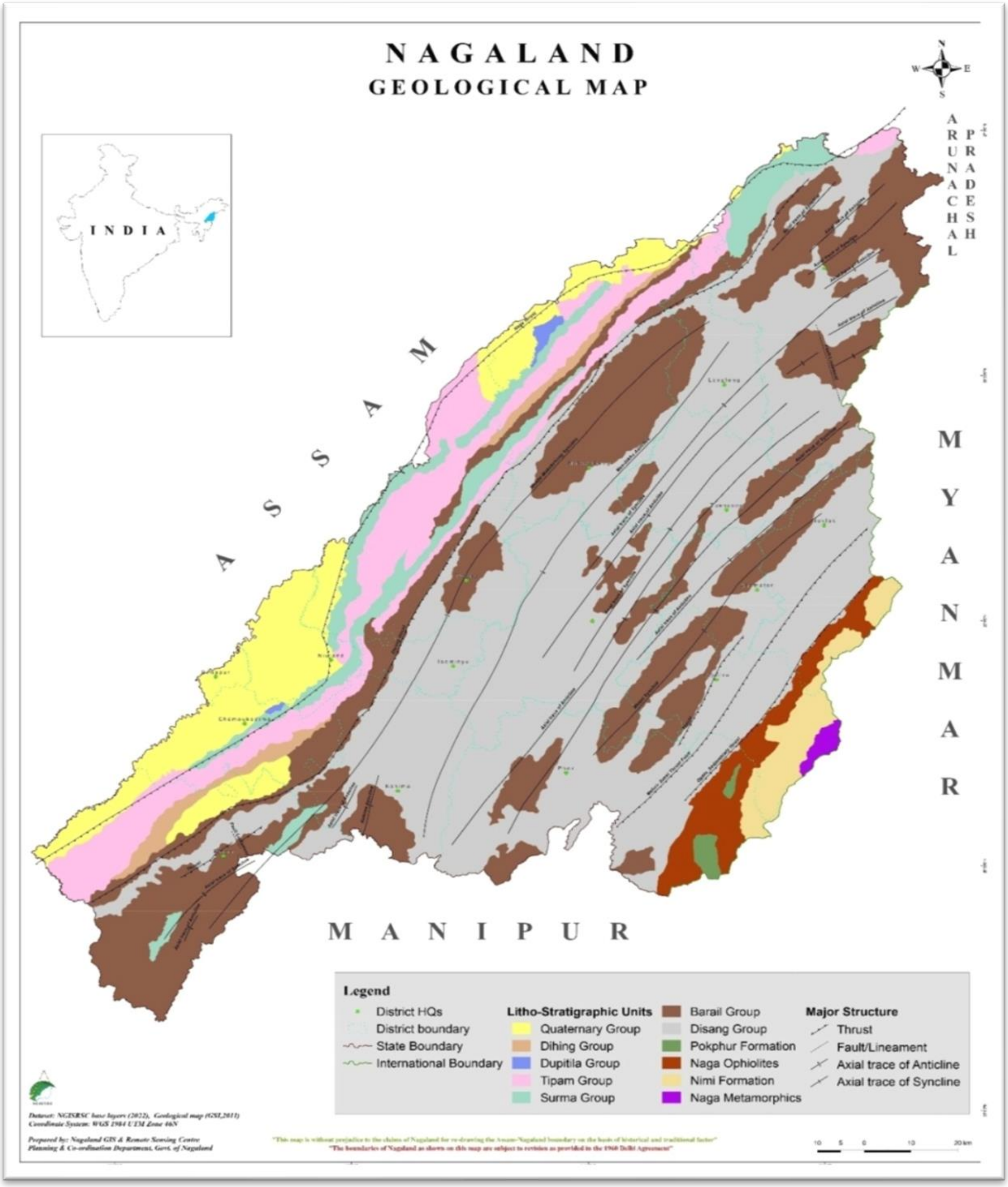


Figure 2.8: Geological map of Nagaland, India (Source: NGISRSC)

Table 2.1: Stratigraphy of Nagaland (Directorate of Geology and Mining, Dimapur, 1978).

Age (approx.)	**Litho-formations in Belt of Schuppen& Intermediate Hills**			**Litho-formations in Eastern High Hills**
Mio-Pliocene	Tipam	Girujan Clay Tipam Sandstone	Girujan Clay Tipam Sandstone	**Jopi Formation** Conglomeratic greywacke and arkose with plant fossils
	Surma			

-- Unconformity --

- Upper Eocene - Oligocene (molassic sediments)	Barail		Tikak Parbat Baragolai Naogaon	**Lower Barail** Fine to medium grained sandstones with plant fossils
Upper Cretaceous-Eocene (flysch sediments)	Disang			**Disang** Shale, slate, and phyllite with calcareous lenses in basal sections and invertebrate and plant fossils in upper sections with brine springs

________________Fault/Thrust ________________

Upper Cretaceous - Lower Eocene (Ophiolite Complex)	**Zepuhu Formation** 1. Chert, quartzites, limestone, greywacke, tuffs, basic volcanics, basic schists, blue schists with ultramafites and other suites noted under 2 2. Gabbro, diorite, quartz diorite, and ultramafites with minor lenses/bodies of rock types noted under 1

________________Fault/Thrust________________

Pre-Mesozoic	**Nimi Formation** Phyllites, quartz-chlorite-sericite schist, other schists, feldspathic quartzite, orthoquartzite, limestone, and cataclastic granite

The Kohima district in the state of Nagaland is characterized by its steep terrain and is composed of rocks from the Disang and Barail groups. These rocks possess a large potential for deformation, as seen in Figure 2.9 and Table 2.2. The town area of Kohima mostly consists of Disang rocks, whereas the southern section of the region is predominantly composed of Barail sediments. Kohima is located inside the Kohima synclinorium, which is a geological formation containing rocks from the Upper Cretaceous period to the present day.

They are a relatively new mobile belt that experienced orogenic/tectonic disturbances at various stages, mostly during the Tertiary era. The rock formations include of shale, carbonaceous, sandstone, siltstone, conglomerate, pebble, and boulders that correspond to the Disang, Barail, Surma, Tipam, Dupitila, and Dihing groups (Directorate of Geology and Mining, 1996).

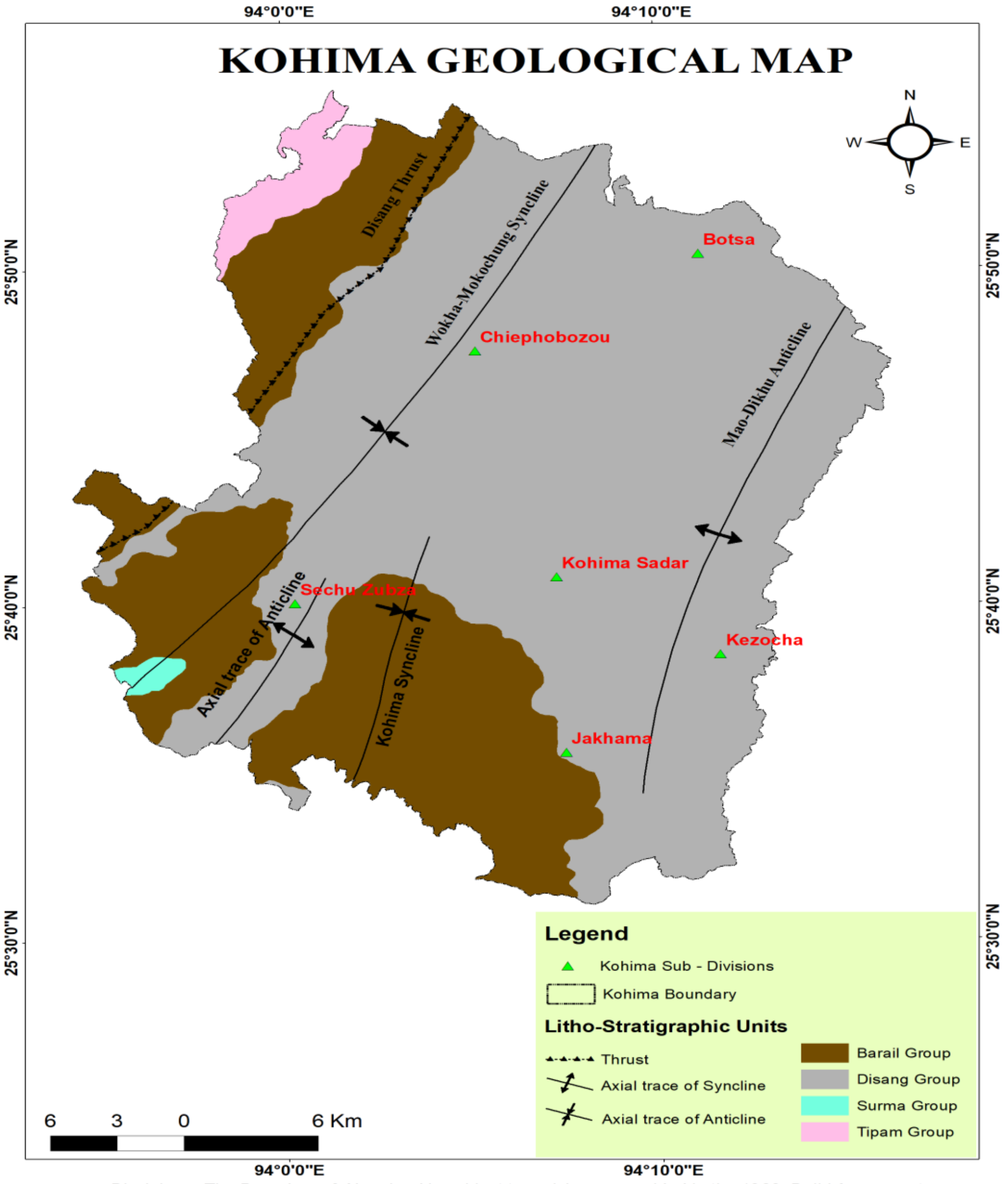


Figure 2.9: Geological map of Kohima district, Nagaland

The geological sequence of Kohima district, as delineated by Mathur and Evans (1964) and subsequently revised by the Geological Survey of India, is as follows:

Table 2.2: Geological succession of Kohima district, Nagaland (Directorate of Geology and Mining, 1996).

Age	Group	Lithology
Recent (Unclassified)	Newer or low-level alluvium	Clay, silt and fine sand

---Unconfirmity---

Pleistocene	Older or high-level alluvium	Clay, medium to coarse sand gravel and boulder deposits

---Unconfirmity---

Pliocene Pleistocene	Dihing	Pebble bed with soft sandy clay, conglomerate, grit and sandstone

---------------------------------------Unconfirmity---

Mio-Pliocene	Cupitila	Sandstone, mottled clay grit and conglomerate

---Unconfirmity---

Upper Miocene	Tipam	Mottled clay, clay, sandy shale coarse & ferruginous sandstones and conglomerate
Lower Miocene	Surma	Shale, sandy shale, siltstone, mudstone, and lenticular coarse ferruginous sandstone, alternation of sandstone & shale with thin conglomerate in the lower part

--Unconfirmity---

Upper Eocene	Barail	Bedded sandstone shale, carb, shale, coal, sandy shale interbedded hard sandstone, well bedded shale with sandstone intercalation at lower bed
Eocene	Disang	Splintery, dark grey shale, siltstone, mudstone with thin and compact sandstone alternation

The Disang group: This assemblage of rocks comprises of dark grey and fissile shales, phyllitic shale, siltstone, sandstone, and khaki or buff-colored shales. It primarily takes place in the central-eastern region of the district. The dark gray and splintery shale have a similar characteristic of spheroidal weathering, which results in the formation of concretionary nodules and a crinkled surface. These shales become crushed and expand when they come in contact with water, particularly in weak zones, making them prone to mud flows. The phyllitic shales are dense and consolidated, and they are located in the lower contour regions of the district. Siltstone is commonly located in the nalla portions and has variations in thickness and color. It is typically found in conjunction with fine and durable sandstone. The sandstones vary in texture from extremely fine to medium and are visible in areas of the nalla where they have well-defined joints and cracks. At higher elevations, the terrain might consist of ferruginous and quartzite formations, which create distinct ridge lines. The khaki-colored shales are located near the apex of hills and are frequently linked to clay.

The Barail groups: The Barail group of rocks is situated above the Disang range and it spans across a significant portion of the southwestern area of the region. The rocks are mostly composed of sand and are found in the lowest layers. They consist mainly of well-layered sandstone.

The Surma groups: The Surma rock formation is positioned above the Barail mountain range and consists primarily of shales and sandstones, with additional conglomerates that decrease in thickness as one moves towards the north. These fossils are located among the layers of the tipam group of rocks in the far northwestern region of the area.

The Tipam groups: The Tipam rock formation is also present in the northern region of the area. It mostly consists of ferruginous sandstone with significant clay layers and is characterized by its substantial thickness.

2.1.3.1. Lineament Density of Kohima district

Lineaments include faults, thrusts, strike ridges, tectonically controlled river valleys, etc. These lineaments are deep underlying geological structures that indicate neotectonic or microseismic activity in the area. Field base geomorphological (multilevel terraces, triangular facets, landslides, etc.) and geohydrological mapping can identify them. Figure 2.10 shows how deep geostructural sections with NE to SW and NW to SE orientations are related with diverse lineaments in the studied region. The primary geostructural lineament in eastern Kohima is the seismically active Disang thrust extending NE to SW. Localized faults that are tectonically active throughout the region run parallel to the Disang thrust and other faults. To determine the impact of different geostructural lineaments in earthquake hazard, a lineament density map of the research area was created. The lineament density ranges from 0.10 km/km2 to 2.00 km/km2 and is grouped into five classes.

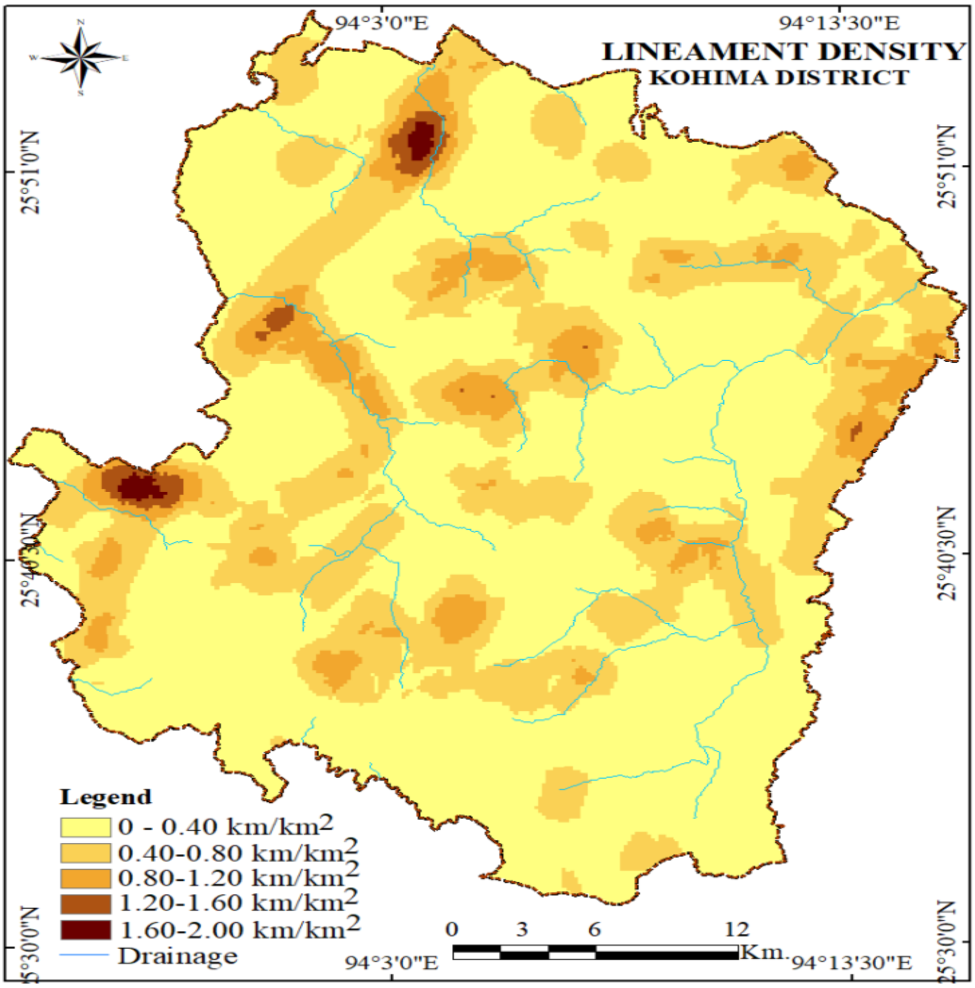


Figure 2.10: Lineament density of Kohima district, Nagaland

2.1.4. Soil

Kohima district has soils that originate from tertiary rocks, namely from two main lithological sections known as the Barail and Disang groups. The Barail group is composed of alternating layers of shales and sandstones, whereas the underlying Disang lithology consists of unfossiliferous shales, slates, and phyllites. A total of twelve soil types were identified and mapped in the area of study based on geo-pedology taxonomy and soil attributes. These soil types were arranged in order of elevation, from lowest to highest, and were shown to be influenced by various geomorphological and lithological factors. The map (Figure 2.11) illustrates the spatial distribution of low relief geomorphology (Piedmonts, Foothills) which consists of Fine, Umbric Dystrochrepts soil and Fine, Loamy Lithic Udorthent soils. These soils are found over lithology composed of Disang group rocks, namely shales, slates, and phyllites. The moderate relief geomorphology in this area consists of upslope hills, downslope hills, terraces, and inter-hill valleys. The soils found here are mainly Fine Loamy Lithic Udorthent, Umbric Dystrochrepts, Fine Typic Paleudults, Typic

Hapludults, and Fine-Loamy soils. These soils overlay the Disang group rocks, which include shales, slates, and phyllites. The high relief geomorphology consists of places with strike ridges, high relief structural hills, and high-middle structural hills. These areas are characterized by soils with a coarse-loamy, typic dystrochrepts composition, as well as fine-loamy, typic dystrochrepts soils. The underlying lithology is composed of Barail group rocks, namely shales and sandstone.

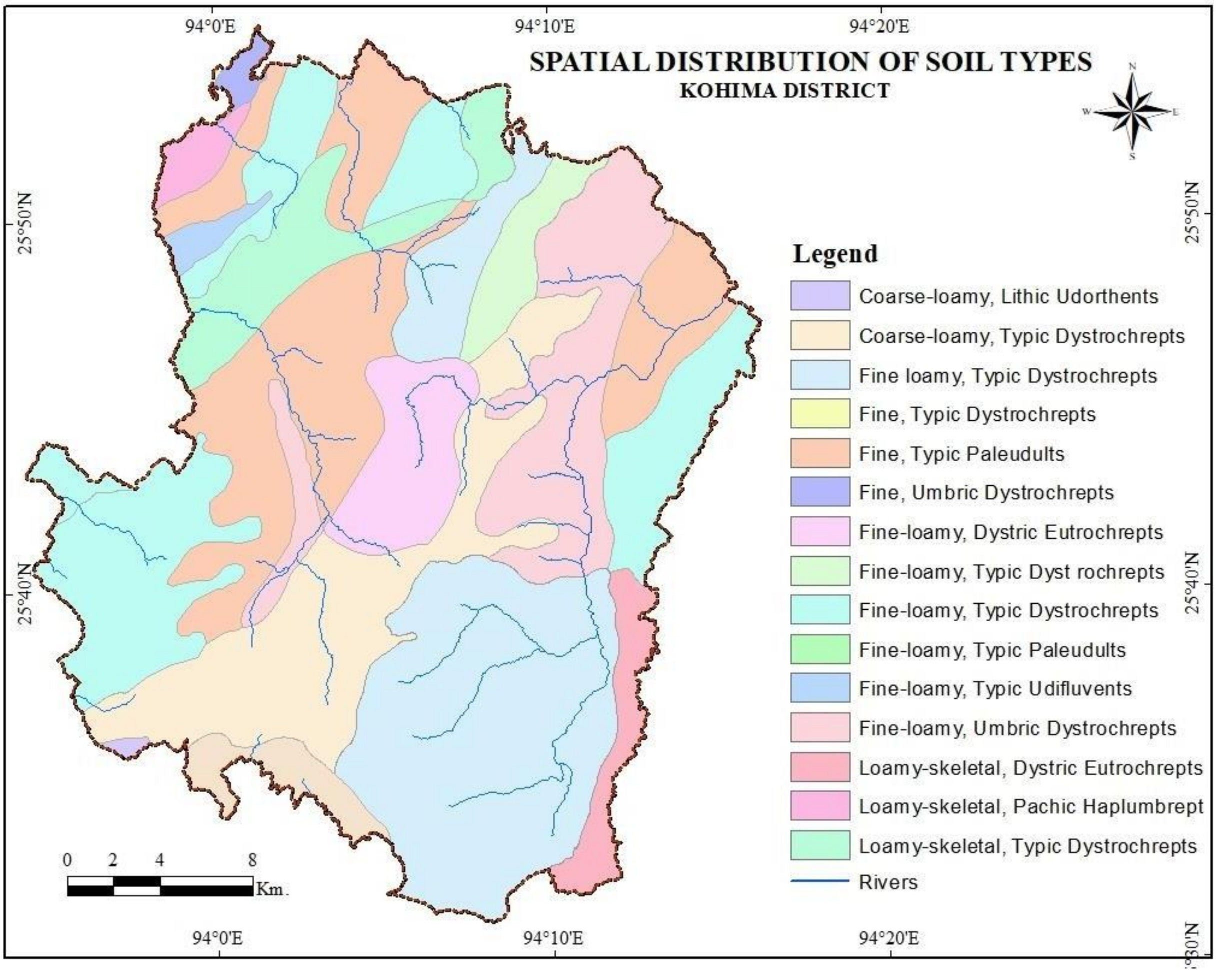


Figure 2.11: Spatial distribution of soil in Kohima district, Nagaland.

Table 2.3: Geo-pedological (Soils) characteristics of Kohima district, Nagaland.

Geology	Geomorphology	Existing soil types
Barail group: Shales, sandstone.	Strike ridge areas, High relief structural hills.	Coarse-loamy,
		Typic Dystrochrepts
	High-middle structural hills.	Typic Dystrochrepts
		Fine-loamy
	Upslope hills and terraces.	Fine-Loamy,
		Umbric Dystrochrepts
Disang group: shales, slates and phyllites.	Down slope hills, River terraces.	Fine-Loamy,
	Inter hill valley.	Typic Hapludults
		Fine, Typic Paleudults
	Piedmonts, Foothills.	Umbric Dystrochrepts soil
		Fine Loamy Lithic Udorthent
	Down slope hills, River terraces.	Fine, Loamy Lithic Udorthents
Tipam group: shales, siltstones, sandstones.	Down slope hills, River terraces.	Fine, Loamy Lithic Udorthents
Surma group: sandstones.	Strike ridge areas, High structural hills.	Coarse-loamy,
		Typic Dystrochrepts

2.1.5. Climate

Climate refers to the long-term patterns of meteorological conditions in a particular place. The most essential element in creating a physical environment is often regarded as the most important aspect. The climate of an area may be characterized by its atmospheric temperature, moisture content, velocity and orientation of air currents, as well as the nature, frequency, and amount of precipitation. Hence, the climate of a location is contingent upon its spatial relationship to many factors. India possesses a remarkable array of climatic areas, with the nation's climate being significantly impacted by the presence of the Himalayas and the Thar desert. As far as eastern Himalaya region is concerned the climate shows rich diversity due to

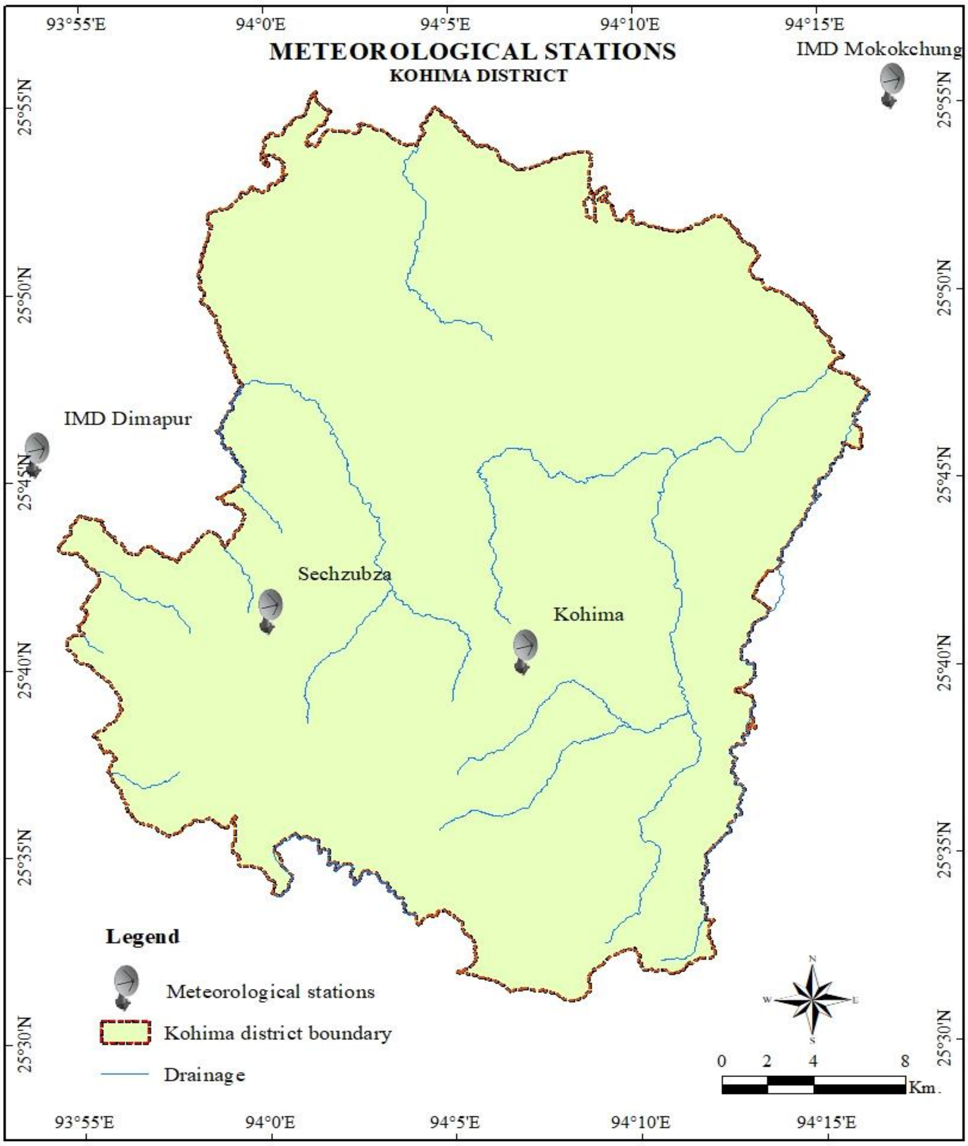


Figure 2.12: Location of meteorological stations in Kohima district, Nagaland.

close geographical association with Bay of Bengal in south and Himalaya Mountain range in north. To comprehend the local microclimatic features of Kohima district and its surrounding areas in Nagaland state, meteorological data spanning a decade (2011-2021) was gathered from four meteorological observatories situated at varying altitudes in the region. These observatories include Kohima (1600 m), Sechu Zubza (2140 m), Dimapur (175 m), and Mokokchung (1085 m) (Figure 2.12). The Kohima and Sechu Zubza meteorological observatories are operated by the soil and water conservation department of the Nagaland state government, while the Dimapur and Mokokchung observatories are operated by the Indian Meteorological Department (IMD), which is a component of the government of India. The Kohima district in northeast India can be classified into four microclimatic zones based on an analysis of meteorological data and an agro-climatic zone map. These zones are determined by the district's elevation, ranging from the lowest point at 204m to the highest point at 2953m. The four zones are as follows: humid tropical (below 900m), humid subtropical (900m-1750m), humid temperate (1750m-2600m), and humid sub-temperate (2600m-3450m) (see Figure 2.13). The spatiotemporal variability of meteorological features within these climatic zones is described as follows.

2.1.5.1. Temperature: The annual mean temperature ranges from below 23ºC in the humid temperate climate zone to above 28ºC in the humid tropical climate zone (Table 2.4). Figure 2.14 and table 2.4 provide an overview of the temperature fluctuations in the district. In August, the greatest temperature reaches 29.09°C, while in January, the lowest temperature drops to 5.14°C. The monthly average minimum and maximum temperatures vary significantly over the region, ranging from a humid tropical climate at lower elevations to a humid temperate climate in higher elevations (Figure 2.14). Based on temporal variability, the year 2017 had the highest maximum temperature of 23.83 ºC and the highest average annual temperature of 18.67 ºC during the selected period (2011-2021). On the other hand, the year 2015 had the lowest minimum temperature of 10.95 ºC and the lowest average annual temperature of 17.02 ºC (Table 2.4).

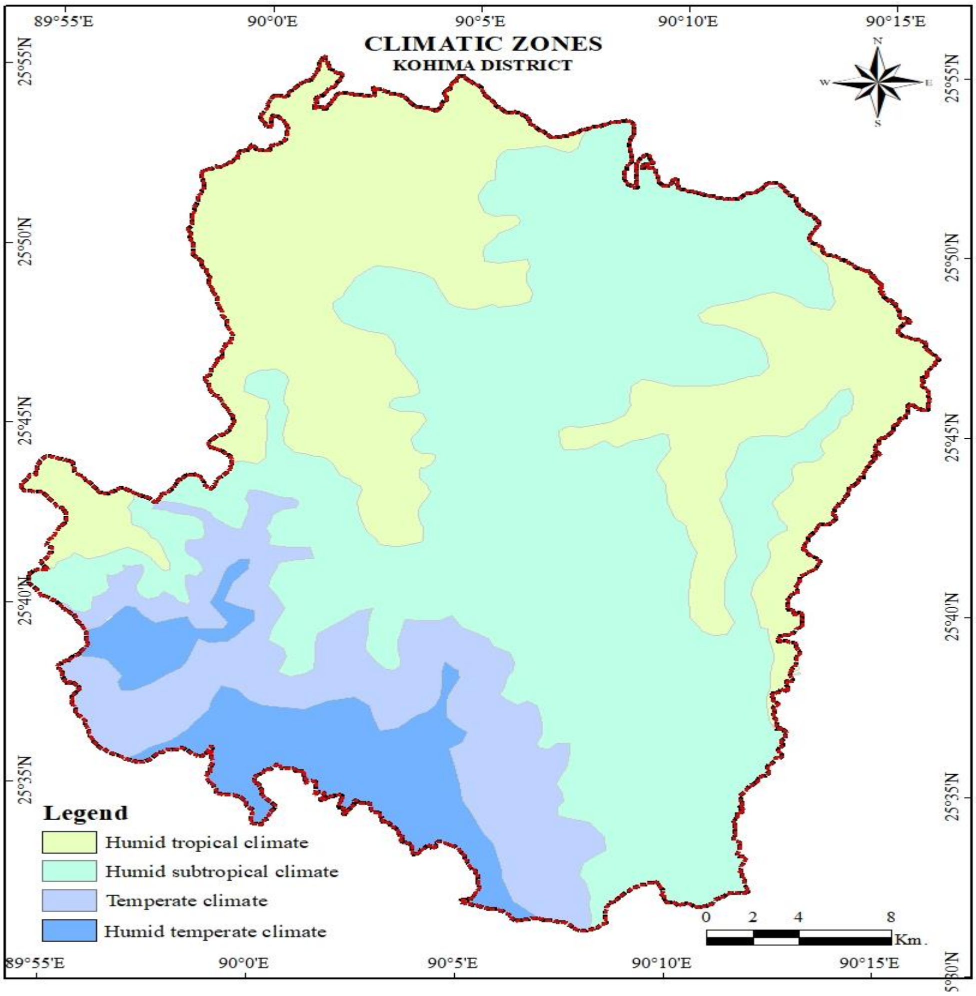


Figure 2.13: Climatic zones of Kohima district, Nagaland.

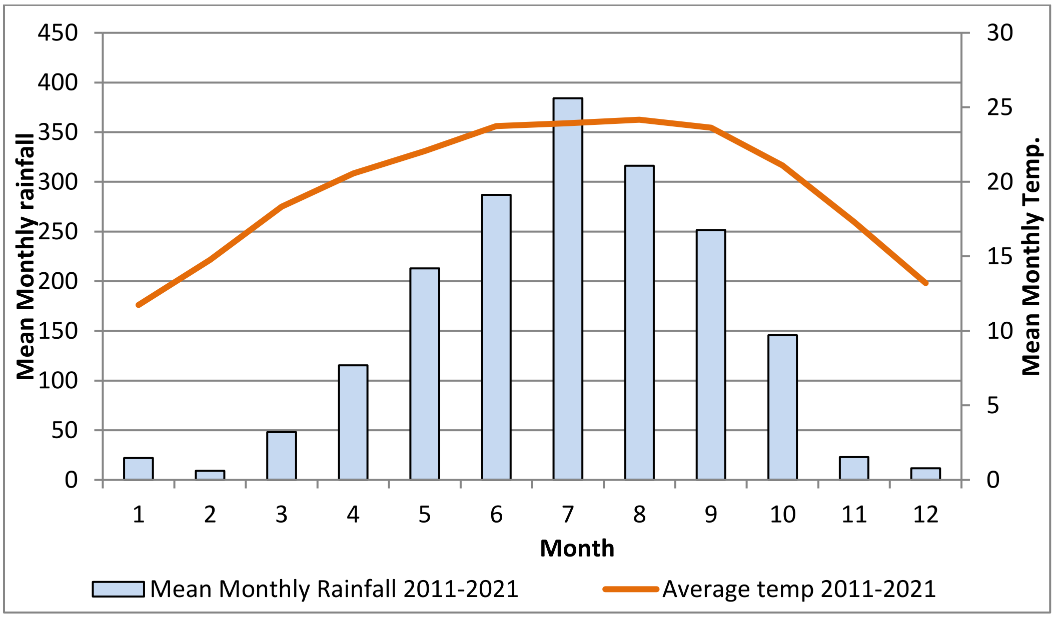


Figure 2.14: Average monthly and annual temperature of Kohima district, Nagaland.

2.1.5.2. Rainfall: The annual average rainfall recorded between years 2011 to 2021 stands at 1659.46 mm in Kohima district (Table 2.5 and Figure 2.15). It varies between less than 1450 mm within humid temperate climate zone to more than 1826.63 mm within the humid tropical climatic zone (Table 2.5). Figure 2.15 and table 2.5 gives us an overview of the rainfall variations in the district where July experiences the highest rainfall at 349.10 mm while the minimum rainfall stands at 10.70 mm in the month of December. Further this monthly average minimum and maximum rainfall varies greatly across the region from humid tropical climatic zone in lower elevations to humid temperate climatic zone in higher elevations (Figure 2.15). Temporal variability suggests that the during selected period (2011-2021) year 2017 experienced the highest rainfall at 2135.60 mm while the year 2021 experienced the least rainfall at 1105.1 mm (Table 2.5). The total number of rainy days in 2020 was recorded to be the highest with a total of 160 days while the year 2021 sees the lowest number of rainy days occurring for just 78 days (Table 2.5). The transition from the highest no. of rainy days in 2020 to the lowest number of rainy days in 2021 provides a vivid picture of massive climate change taking place in the region.

Table 2.4: Annual and monthly maximum, minimum and average temperature of Kohima district, Nagaland (2011-2021)

(Source: Directorate of Soil and Water Conservation, Kohima, Nagaland).

Year		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
2011	Max	14.9	19.1	23.4	24	24.6	25	24.5	25.8	25.6	24	20.9	15.6	22.28
	Min	4.1	6.7	9.7	12.7	14.6	16.9	17	16.4	16.4	13.5	8	5.2	11.76
	Average	9.5	12.9	16.55	18.35	19.6	20.95	20.75	21.1	21	18.75	14.45	10.4	17.02
2012	Max	14.7	18.8	21.9	24.7	25.9	25.4	25.7	26.2	25.3	23.4	21.3	18.5	22.65
	Min	3.9	6.3	10	13	14.8	16	17.3	16.8	16.1	12.4	8	5.7	11.69
	Average	9.3	12.55	15.95	18.85	20.35	20.7	21.5	21.5	20.7	17.9	14.65	12.1	17.17
2013	Max	16.7	21.8	24.3	25.4	24.8	27.2	26.4	27	26	25.1	22.4	17.7	23.73
	Min	4.2	7.2	9.8	12.5	14.3	16.1	16.6	16.6	15.7	12.6	7.4	4.1	11.42
	Average	10.45	14.5	17.05	18.95	19.55	21.65	21.5	21.8	20.85	18.85	14.9	10.9	17.57
2014	Max	17.1	18.5	22.5	27.6	26.9	26.5	26.7	25.6	25.3	24.5	21.9	18.8	23.49
	Min	4.2	7.2	9.8	12.5	14.3	16.2	16.6	15.8	15.4	12.2	8.4	5	11.46
	Average	10.65	12.85	16.15	20.05	20.6	21.35	21.65	20.7	20.35	18.35	15.15	11.9	17.47
2015	Max	17.2	19.1	24.6	24.7	25.8	27.1	26.2	25.6	25.5	22.4	23.1	17.3	23.21
	Min	4.7	5.9	9.9	11.2	13.5	15.5	16	15.7	15.2	12.4	7.8	3.6	10.95
	Average	10.95	12.5	17.25	17.95	19.65	21.3	21.1	20.65	20.35	17.4	15.45	10.45	17.08
2016	Max	15.8	20.4	24.5	25.5	24.6	25.1	25.6	27	25.4	25.3	22.7	20.9	23.56
	Min	2.9	6.6	9.8	12.6	14.5	18.4	19.5	19.7	18.7	16.2	10.8	9.2	13.24
	Average	9.35	13.5	17.15	19.05	19.55	21.75	22.55	23.35	22.05	20.75	16.75	15.05	18.40
2017	Max	19.8	22.5	21.7	24.2	25.6	25.9	26.3	26.5	25.6	25.9	22.7	19.3	23.83
	Min	6.8	8.6	9.9	13.3	16.4	17.4	18.5	18.1	18.6	16.1	11	7.5	13.51
	Average	13.3	15.55	15.8	18.75	21	21.65	22.4	22.3	22.1	21	16.85	13.4	18.67
2018	Max	18	19.5	23.5	24	24.2	26	26.5	26.9	26.5	23.4	22.6	19.9	23.41
	Min	6	7.9	10.9	12.9	14.4	17.7	18.4	18.7	18.1	13.3	10.4	5.3	12.83
	Average	12	13.7	17.2	18.45	19.3	21.85	22.45	22.8	22.3	18.35	16.5	12.6	18.12
2019	Max	18	20.9	22.1	24.1	27.7	27	26	28.2	25.9	22.7	22.3	17.9	23.56
	Min	5.1	6.5	10.5	12.4	15.7	17.9	17.8	18.2	17.8	14.5	11.1	6.2	12.80
	Average	11.55	13.7	16.3	18.25	21.7	22.45	21.9	23.2	21.85	18.6	16.7	12.05	18.18
2020	Max	15.4	17.6	21.9	21.9	24.6	25.1	24.1	26.1	26.4	23.9	21.8	17.2	22.16
	Min	4.9	8.1	11.5	12	14.6	17.2	17.8	18.6	18.2	17.2	10.7	6	13.06
	Average	10.15	12.85	16.7	16.95	19.6	21.15	20.95	22.35	22.3	20.55	16.25	11.6	17.61
2021	Max	15.8	19.9	23.7	26.2	24.7	27.3	27.2	26	27.4	25.7	21.4	17.3	23.55
	Min	4.6	6.4	11	14.1	14.8	18	18.1	17.9	17.8	15.5	9.5	6.1	12.81
	Average	10.2	13.15	17.35	20.15	19.75	22.65	22.65	21.95	22.6	20.6	15.45	11.7	18.18
Average	Max	12.08	15.17	18.38	20.22	21.33	22.78	22.81	23.18	22.64	20.58	17.38	13.45	19.16
	Min	13.57	16.24	19.45	21.49	22.53	23.55	23.59	23.79	23.29	21.12	18.35	14.87	20.15
	Average	6.71	9.36	12.60	14.78	16.59	18.70	19.11	19.19	18.75	16.12	11.76	7.98	14.30

Table 2.5: Annual and monthly total rainfall and no. of rainy days of Kohima district, Nagaland (2011-2021)
(Source: Directorate of Soil and Water Conservation, Kohima, Nagaland).

Year	Parameters	Months												Total
		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
2011	Total Rainfall	9.8	5.2	56.8	34.9	265.6	308.2	437.7	239.9	336.3	31.7	9.7	0	1735.8
	No. of Rainy days	2	1	5	5	19	27	28	21	23	7	3	0	141
2012	Total Rainfall	32.7	15.2	49.2	81.5	130.8	218.8	295.7	258.7	123.6	124.3	40.2	0	1370.7
	No. of Rainy days	9	3	10	11	9	22	24	21	23	11	3	0	146
2013	Total Rainfall	0	0	45.2	115.4	332.5	298.2	350.9	268.5	226.3	112.1	0	0	1749.1
	No. of Rainy days	0	0	6	11	23	24	29	21	22	15	0	0	151
2014	Total Rainfall	0	16.8	31.8	77.6	145.5	139	332.4	350.6	231.4	58.2	0	0	1383.3
	No. of Rainy days	0	3	6	9	18	24	25	28	20	0	0	0	133
2015	Total Rainfall	25	18.4	18.4	200.7	50.3	224.1	316.4	374.1	212.2	74	2.1	5.6	1521.3
	No. of Rainy days	2	4	5	24	16	21	24	26	15	7	3	2	149
2016	Total Rainfall	20	5.6	36.2	97.8	243.8	317.2	255.2	256.4	242.7	204.2	72.8	1.4	1753.3
	No. of Rainy days	4	3	9	14	18	25	24	16	22	14	4	1	154
2017	Total Rainfall	2.2	0.8	93	163.7	234.6	326.9	482.1	250.4	340.6	204	5.4	31.9	2135.6
	No. of Rainy days	2	1	8	10	15	23	25	19	23	15	3	2	146
2018	Total Rainfall	13.2	3.6	45	127.6	279.2	338.1	568.4	359.4	139.6	85.2	1.2	65.4	2025.9
	No. of Rainy days	2	1	8	16	20	27	25	17	15	5	1	3	140
2019	Total Rainfall	80.6	15.4	58.2	83	175	208.1	286.4	355.9	266.6	212.6	37.2	0	1779
	No. of Rainy days	2	3	8	14	12	20	28	20	23	16	3	0	149
2020	Total Rainfall	35.8	9.4	21	130.2	181.6	319.6	328	215.6	154	237.6	62.2	0	1695
	No. of Rainy days	6	3	4	17	13	24	28	22	19	20	4	0	160
2021	Total Rainfall	0.3	0	25.2	42.4	78.2	171.6	187.4	233.2	241.8	111.4	0	13.6	1105.1
	No. of Rainy days	0	0	1	2	7	11	16	19	13	7	0	2	78
Average	Total Rainfall	**19.9**	**8.2**	**43.6**	**104.9**	**192.4**	**260.8**	**349.1**	**287.5**	**228.6**	**132.3**	**20.9**	**10.7**	**1659.4**
	No. of Rainy days	**3**	**2**	**6**	**12**	**15**	**23**	**25**	**21**	**20**	**11**	**2**	**1**	**141**

Table 2.6: Average monthly and annual humidity (R/H in %) of Kohima district, Nagaland (2011-2022) (Source: Directorate of Soil and Water Conservation, Kohima, Nagaland).

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
2011	55.7	43.8	45.6	54.8	74.7	85.9	87.4	81	78	69.6	52.4	55.8	65.39
2012	66.4	50.8	47.7	64.1	67.3	80.2	81.6	78.6	83.3	74.5	64.9	63.6	68.58
2013	54.8	43.5	38.9	48.2	74.4	73.5	84.6	80.5	76.9	71.7	61.5	57.5	63.83
2014	65.2	67.5	70.7	63.5	79.8	82.5	83.2	85.8	85.8	75	71.4	54.2	73.72
2015	74.9	78	80.2	84.6	86.1	87.1	87.3	89.3	88.2	84.2	78.7	78.9	83.13
2016	75.9	74.6	70.9	69.6	82.3	87.1	89.6	86.2	91.2	85.7	68.7	61.6	78.62
2017	68.0	68.4	80.9	81.0	86.9	92.1	90.5	88.6	90.6	89.7	73.7	68.4	81.57
2018	73.9	74.8	71.0	82.4	88.0	89.4	90.2	88.8	85.0	79.4	73.0	76.3	81.02
2019	74.2	83.8	80.6	82.8	85.2	87.7	90.2	86.0	86.4	86.3	80.3	84.8	84.03
2020	80.1	71.2	65.6	77.4	83.0	87.0	88.5	87.5	87.6	85.2	70.5	61.5	78.76
2021	68.9	68.4	74.4	73.5	82.4	85.2	87.6	87.0	87.5	85.1	79.5	76.4	79.66
Average	**75.8**	**72.48**	**72.65**	**78.19**	**89.01**	**93.77**	**96.07**	**93.93**	**94.05**	**88.64**	**77.46**	**73.9**	**83.83**

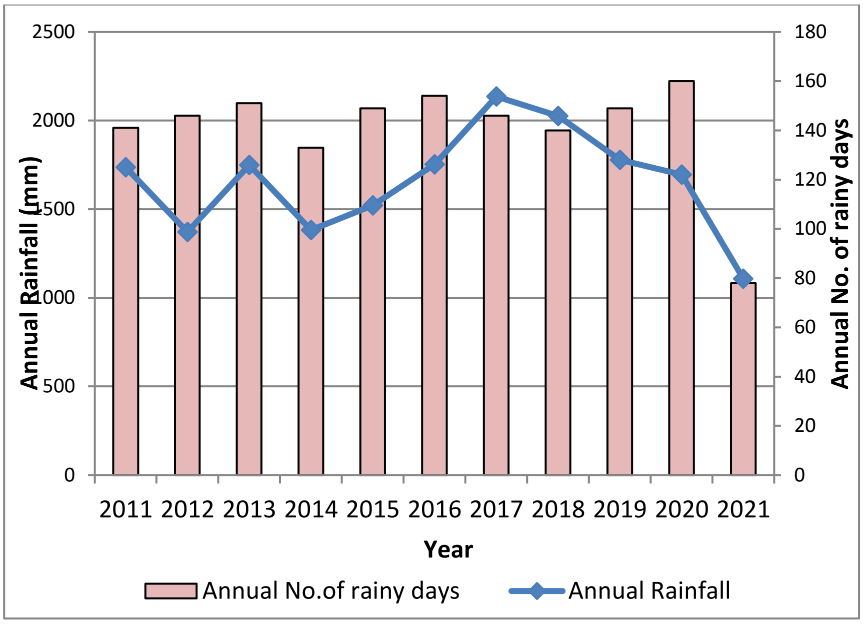


Figure 2.15: Average monthly and annual rainfall of Kohima district, Nagaland.

2.1.5.2 Humidity: The annual average humidity recorded between year 2011 to 2021 stands at 83.83% in Kohima district (Table 2.6 and Figure 2.16). It varies between less than 79.25% within humid temperate climate zone to more than 95 within the humid tropical climatic zone (Table 2.6). Figure 2.16 and table 2.6 gives us an overview of the humidity variations in the district where July experiences the highest humidity at 96.07% while the minimum humidity stands at 72.65% in the month of February. Further this monthly average minimum humidity and maximum humidity varies greatly across the region from humid tropical climatic zone in lower elevations to humid temperate climatic zone in higher elevations (Figure 2.16). It can be seen from the table 2.5 that humidity is highest usually in the month of July where temperature and rainfall is also recorded to be at its peak as discussed in figure 2.16. A diagrammatic representation of the relationship among temperature, rainfall and humidity is shown below in figure 2.16 to give a clear representation of the mechanism of the climatic elements in Kohima from 2011-2021.

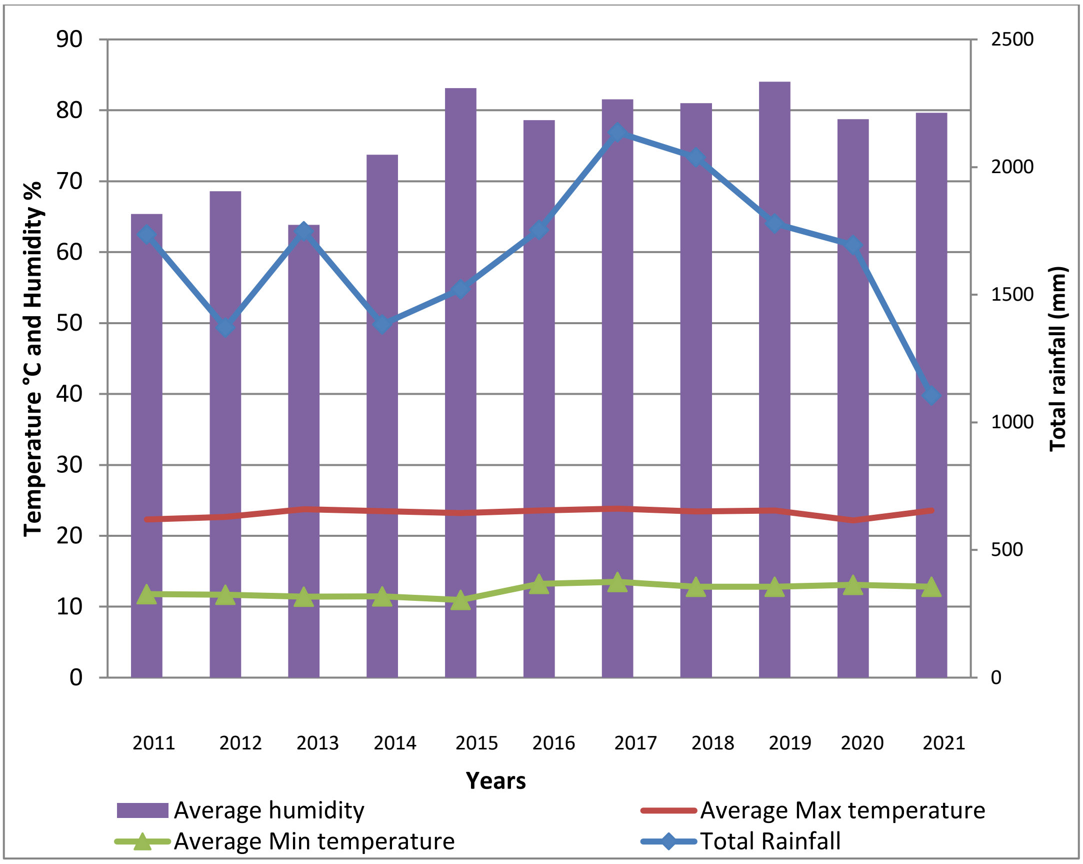


Figure 2.16: Trends of average rainfall, temperature and humidity in Kohima district, Nagaland from 2011 to 2021.

2.1.6. Drainage

The rivers of Nagaland flow either into the Brahmaputra in the west in Assam or into the Chindwin in the east in Myanmar. There are two prominent rivers in Nagaland: the Dhansiri river, which flows from south to north and eventually joins the Brahmaputra river, and the Doyang river, the largest river in Nagaland, which also merges with the Brahmaputra river. Two rivers, the Dzii and the Sidzii, flow in parallel in the upper part of Doyang, forming this waterway. Additional significant rivers in Nagaland include the Tsurang river, which meanders through the Changki Valley, the Milak river originating from Mokokchung, and the Dikhu river that has its source near Zunheboto district, the Tizit river that has its source in the

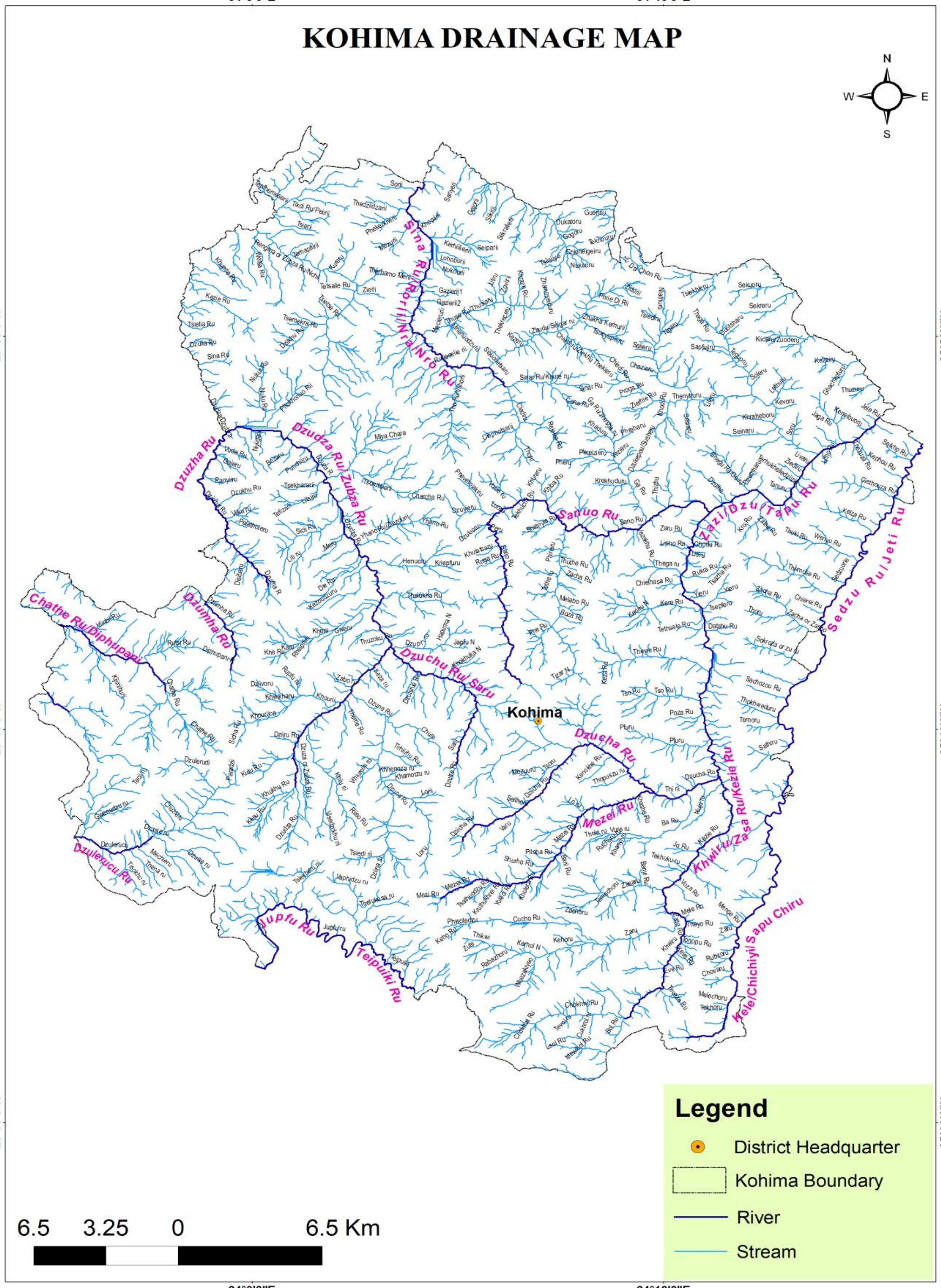


Figure 2.17: Drainage pattern of Kohima district, Nagaland.

northernmost point of Nagaland in Mon district, where the Zungki, Likimro, and Lanye rivers converge and flow into the Chindwin River. Figure 2.17 shows that Kohima is intersected by numerous streams. The drainage system is primarily composed of tributaries of the Dhansiri and Doyang rivers, which are part of the Brahmaputra system. The primary drainage system that regulates the hydrogeological conditions in and around Kohima is the Dzuza ru (Figure

2.17). The Dzuza ru or Zubza ru meanders through Zubza, giving rise to tributaries such as Die ru, Khe ru, Chu ru, Khu ru, Dzutre ru, and Dzuna ru. Another river that flows in the northeast direction is Dzulu or Chiedi ru. It forms tributaries along its path, most of which flow in the southern part of the district. These tributaries include Zachar ru, Dzunaru, Jagu ru, Ghegu ru, Dzulu, Theyie ru, tso ru, Pfu ru, and Mezi ru.There are many intersecting streams in the district, but most of them dry up during the winter season.

2.1.7. Natural Vegetation

Understanding the diverse range of natural vegetation is crucial as it is intricately linked to the environment, with variations based on climate, soil, and topography. Kohima has a vegetation area of 801.40 km2, making up approximately 81.86% of the region. Considering the spatial variability of average annual temperature and vegetation cover in the study region, it can be divided into the following four categories (Figure 2.18):

i. Tropical forests are characterized by high average annual temperatures exceeding 30°C.
ii. Humid tropical forests have average temperatures ranging from 25°C to 30°C.
iii. Sub temperate forests experience average annual temperatures between 10°C and 25°C.
iv. Alpine forests are found in areas with average annual temperatures below 10°C. On the other hand, considering the rainfall pattern across the Kohima district in Nagaland state, the vegetation cover of the study region can be categorized into four groups. These categories include:

i. Evergreen forest, characterized by rainfall exceeding 200cm.
ii. Monsoon deciduous, with rainfall ranging from 100-200cm.
iii. Drier/Deciduous/Tropical, where rainfall ranges from 50-100cm.
iv. Dry thorny, for areas with rainfall less than 50cm.

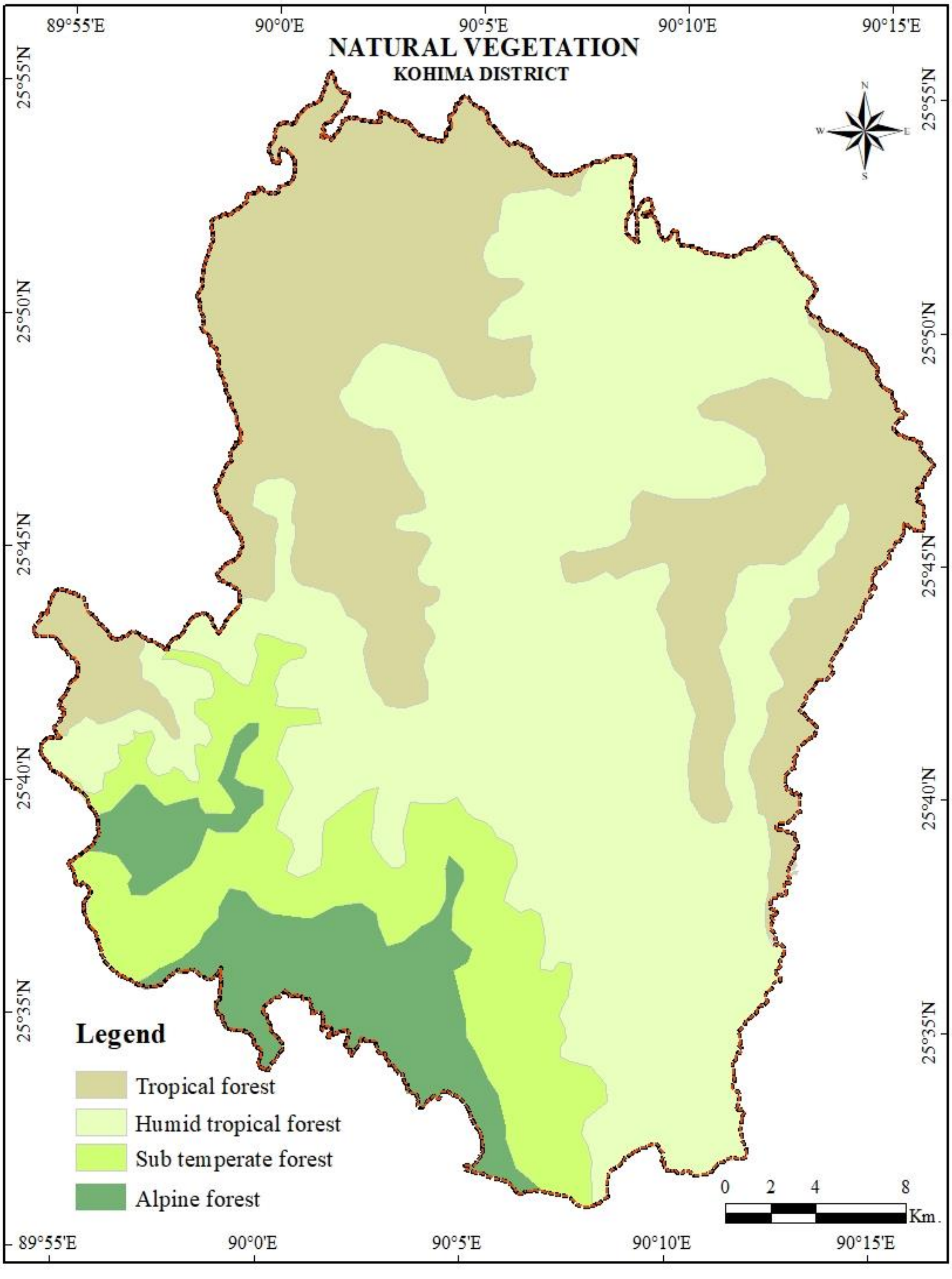


Figure 2.18: Spatial variability and types of natural vegetation in Kohima district, Nagaland

2.2. Human Geography of the Study Area

Human geography is the study of individuals, societies, customs, economics, and their relationship to the environment within a specific geographic area. The discipline of human geography has experienced progressive growth, with its many components expanding throughout time. The study of human beings and the environment is inherently interconnected, as the environment significantly impacts all aspects of human existence. An individual's identity is shaped by their surroundings and their ability to adjust to them. Thus, in the field of human geography, the understanding of the interconnection between humans and their environment is essential. The fundamental focus of Human Geography is the impact of the physical environment on the socio-cultural environment of human beings. The survival of a human being relies not only on the basic necessities of existence such as oxygen, water, and food, but also on the avenues for social, intellectual, moral, and spiritual development. Humans are accountable for all the changes and conflicts in the environment, driven by both necessities and desires. In a contemporary technological society, humans play a significant role in shaping the Earth's surface, causing the formation of new landscapes and landforms. However, this human activity also leads to the emergence of natural hazards such as landslides, floods, and soil erosion. Additionally, it causes the complete destruction of existing ecosystems and habitats for plants and animals, resulting in a rapid degradation of natural resources (Rawat, 2011). Hence, when examining the geography of a particular region, analysing the cultural setting, population, land utilization, and cultural scenery of the area allows for a more profound understanding of its functioning and inherent characteristics. This comprehensive perspective offers a broader understanding of the region's identity and the circumstances at hand. Considering all of these elements, this study examines the main human-caused factors that impact the socioeconomic susceptibility to geomorphic hazards. These factors include the pattern of land use, cultural characteristics, livelihood, educational attainment, and community knowledge of geomorphic hazards and their associated socio-economic risks.

2.2.1. Anthropogenic Landscape and Land-use Pattern

Land use pattern, also known as anthropogenic landscape, primarily consists of human settlements, agricultural land, urban land, service centres, road network, canals, dams, and surrounding natural resources such as woods, grassland, water springs, ponds, streams, rivers, etc. In terms of the research area, the land use pattern is predominantly influenced by the geo-physical factors such as relief, slope gradient, slope aspects, geology, and geomorphology, as well as the ecological factors including rainfall, temperature, soil types, and water availability. These features have a significant impact on the land use throughout the region. The spatial distribution of land use and land cover indicates that the majority of the higher elevation regions are characterized by forest and shrub vegetation, while the lower slopes and valleys are dominated by urban and suburban development and agricultural land, respectively (Figure 2.19). The land use map statistics are summarized in table 2.7. The data suggests that approximately 82% of the study region's total area (978.96 km2) is comprised of natural landscape, including 18% dense forests, 63% open forest land, 0.39% water bodies, and 0.81% shrubs land. The remaining 18.14% of the area is classified as anthropogenic landscape, consisting of 8.72% build-up area, 1.26% wasteland, and 8.16% agricultural land.

Table 2.7: Land use pattern of Kohima district, Nagaland.

Land Use/ Land cover Classes		**Area**	
		km^2	**%**
Natural landscape (NL)	Dense Forest	176.25	18.00
	Open Forest	613.47	62.67
	Water bodies	3.79	0.39
	Shrubs land	7.89	0.81
	Total (NL)	*801.4*	*81.86*
Human Landscape (HL)	Build up area	85.32	8.72
	Waste Land	12.38	1.26
	Agricultural land	79.86	8.16
	Total (HL)	*177.56*	*18.14*
Total (NL+HL)		**978.96**	**100**

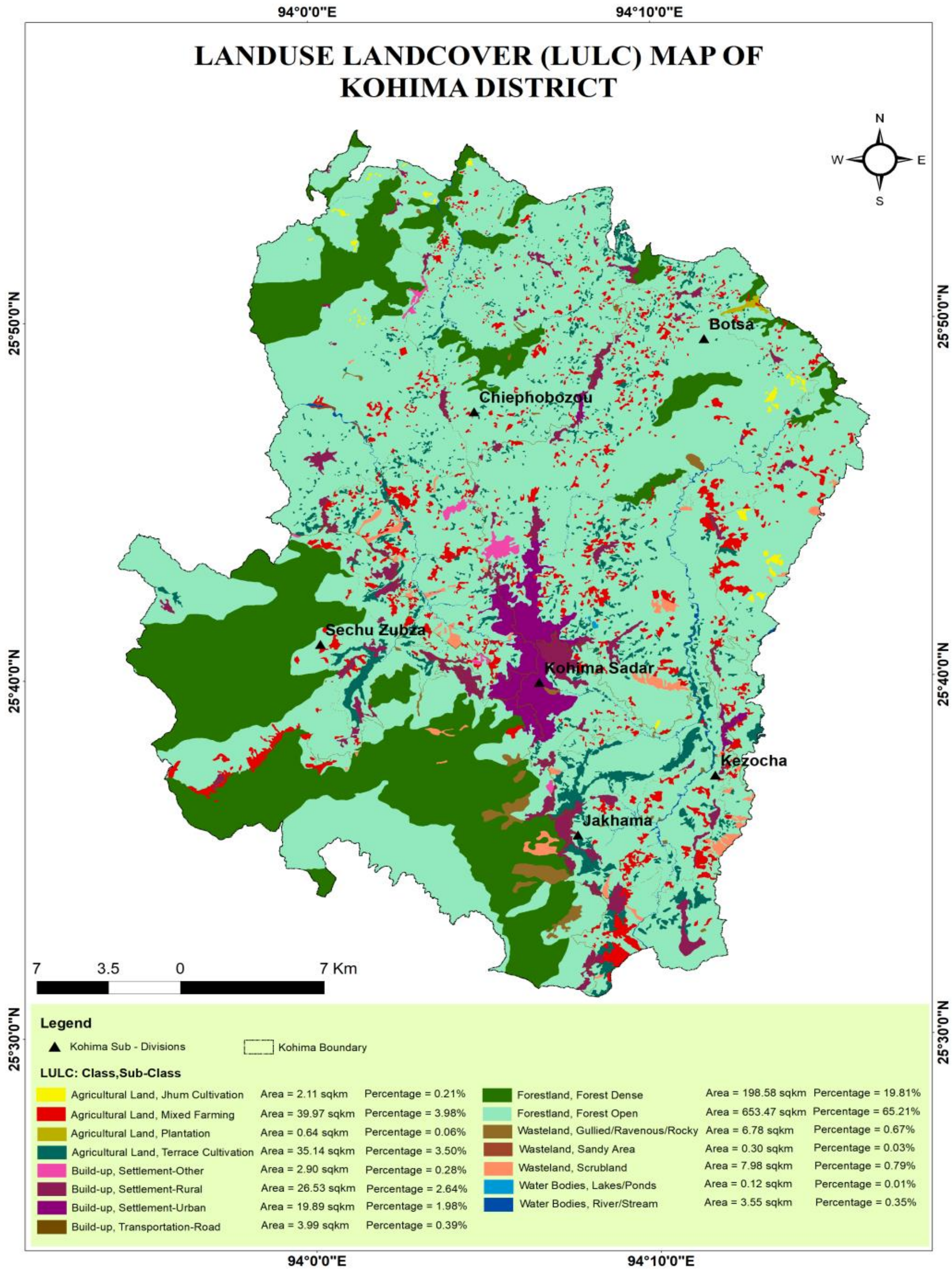


Figure 2.19: Land use Land cover map of Kohima district, Nagaland.

2.2.2. Cultural profile

Nagaland is mostly recognized for its tribal culture, especially in rural regions. However, in terms of religious structure, it showcases a significant cultural variety. According to the census statistics from 2011 and the population projections from 2023, Christians are the majority in Kohima district. Table 2.8 and figure 2.20 illustrate that within the entire population of Kohima district, the largest proportion of 87.67% (185,114 individuals) identifies with the Christian culture. The Hindu religion represents the second greatest proportion of the population, while the Jain faith represents the smallest share, accounting for only 0.03% (63 individuals) of the total population. The district's population is comprised of 1.64% (3463) Muslims, 0.37% (781) Sikhs, and 0.57% (1204) Buddhists, among other significant religions.

Table 2.8: Religion composition of Kohima district, Nagaland (Source: District Census handbook Kohima, 2022).

Sl. No.	Religions	Population	% of total population
1	Hindu	20080	9.51
2	Muslim	3463	1.64
3	Christian	185114	87.67
4	Sikh	781	0.37
5	Buddhist	1204	0.57
6	Jain	63	0.03
7	Others	443	0.21
Total		**211149**	**100**

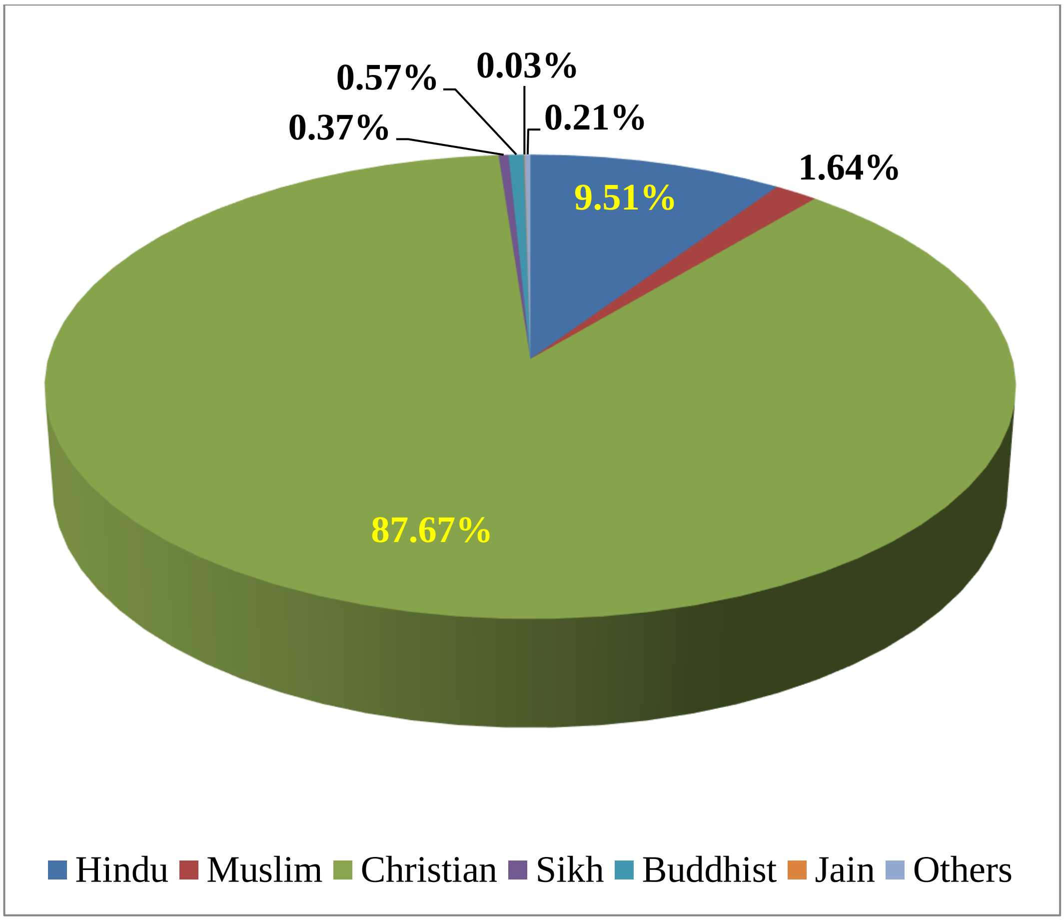


Figure 2.20: Religion composition of Kohima district, Nagaland

2.2.3. Demographic Profile

2.2.3.1. Spatial distribution and density of population: The population, or demographic composition, of an area is a crucial determinant in comprehending the socio-economic state of a place. Based on the 2011 census data, the overall population of Nagaland is 1,980,602. Dimapur has the biggest population share, accounting for 19.17% of the total population, while Kohima ranks second in terms of district-wise population share. Kohima, as per the 2011 census, is divided into 6 circles. Among these, Kohima Sadar has the largest population share in the district, accounting for 55.35% of the total population with a count of 116,870. On the other hand, Botsa circle has the lowest population count of 6,695, making up just 3.17% of the total population. The remaining four circles fall in between these two extremes. The population distribution of Jakhama, Chiephobozou, Sechu-zubza, and Kezocha accounts for 16.12% (34056), 9.33% (19692), 8.23% (17369), and 7.80% (16467) accordingly, as shown in Table 2.9 and Figure 2.21. The population density in Kohima circle ranges from a maximum of 1471 persons per square kilometer in Kohima Sadar to a minimum of 59 persons per square kilometer in Botsa circle. In the other four circles, Jakhama, Chiephobozou, Sechu-zubza, and Kezocha, the population density is 284 persons per square kilometer, 64 persons per square kilometer, 65 persons per square kilometer, and 150 persons per square kilometer, respectively (Table 2.9). Figure 2.22 displays the regional distribution of population density in the Kohima district of Nagaland.

Table 2.9: Circle-wise population distribution and density of Kohima district, Nagaland, 2011 (Source: District Census handbook Kohima, 2011).

Sub district's name	**Population (year 2011)**	**Percentage to total population**	**Population density (Persons/km^2)**
Kohima Sadar	116870	55.35	1471
Jakhama	34056	16.12	284
Chiephobozou	19692	9.33	64
Sechu-Zubza	17369	8.23	65
Kezocha	16467	7.80	150
Botsa	6695	3.17	59
Total	**211149**	**100**	**211**

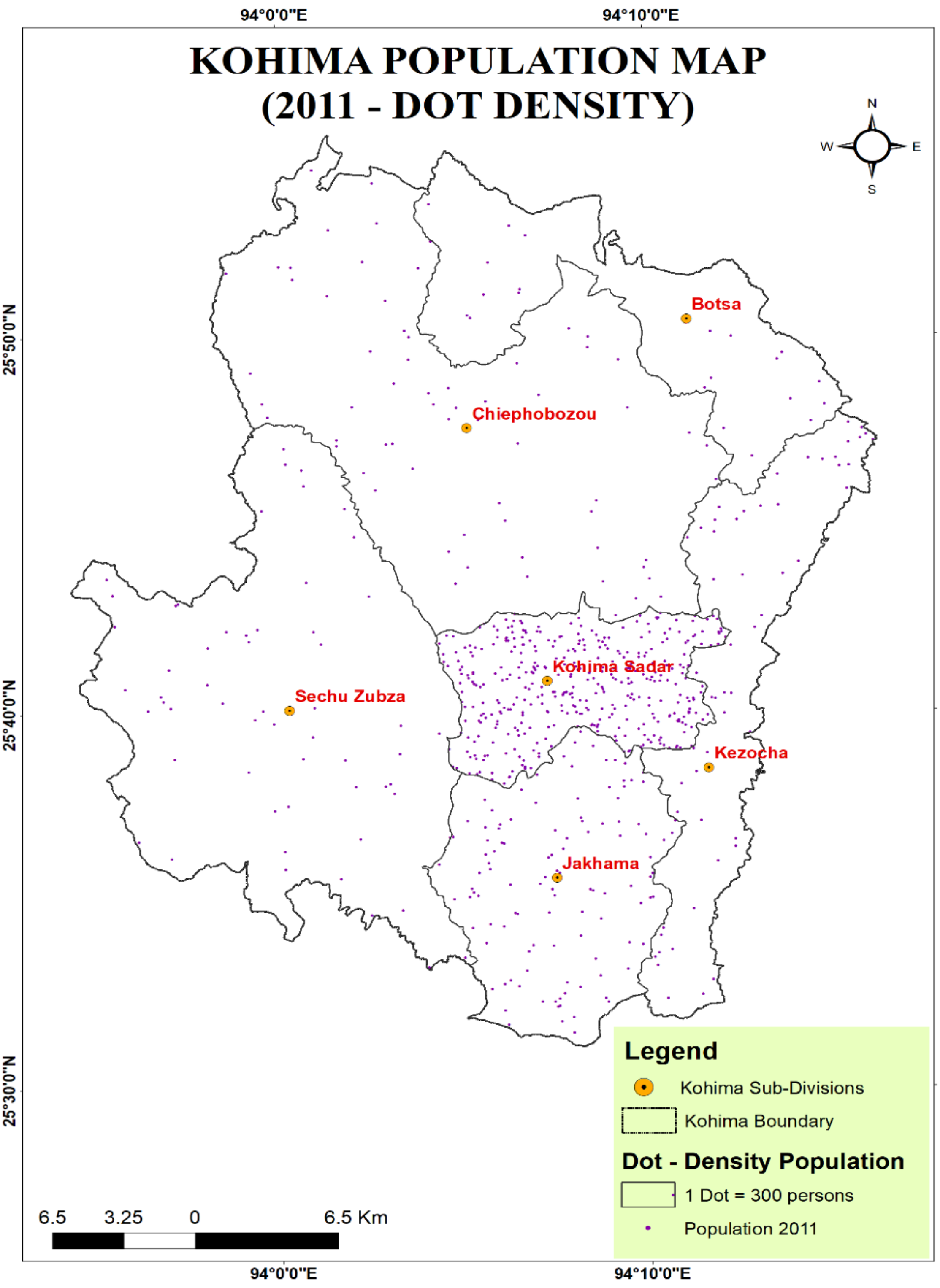


Figure 2.21: Spatial distribution (dot method) of population of Kohima district, Nagaland, 2011.

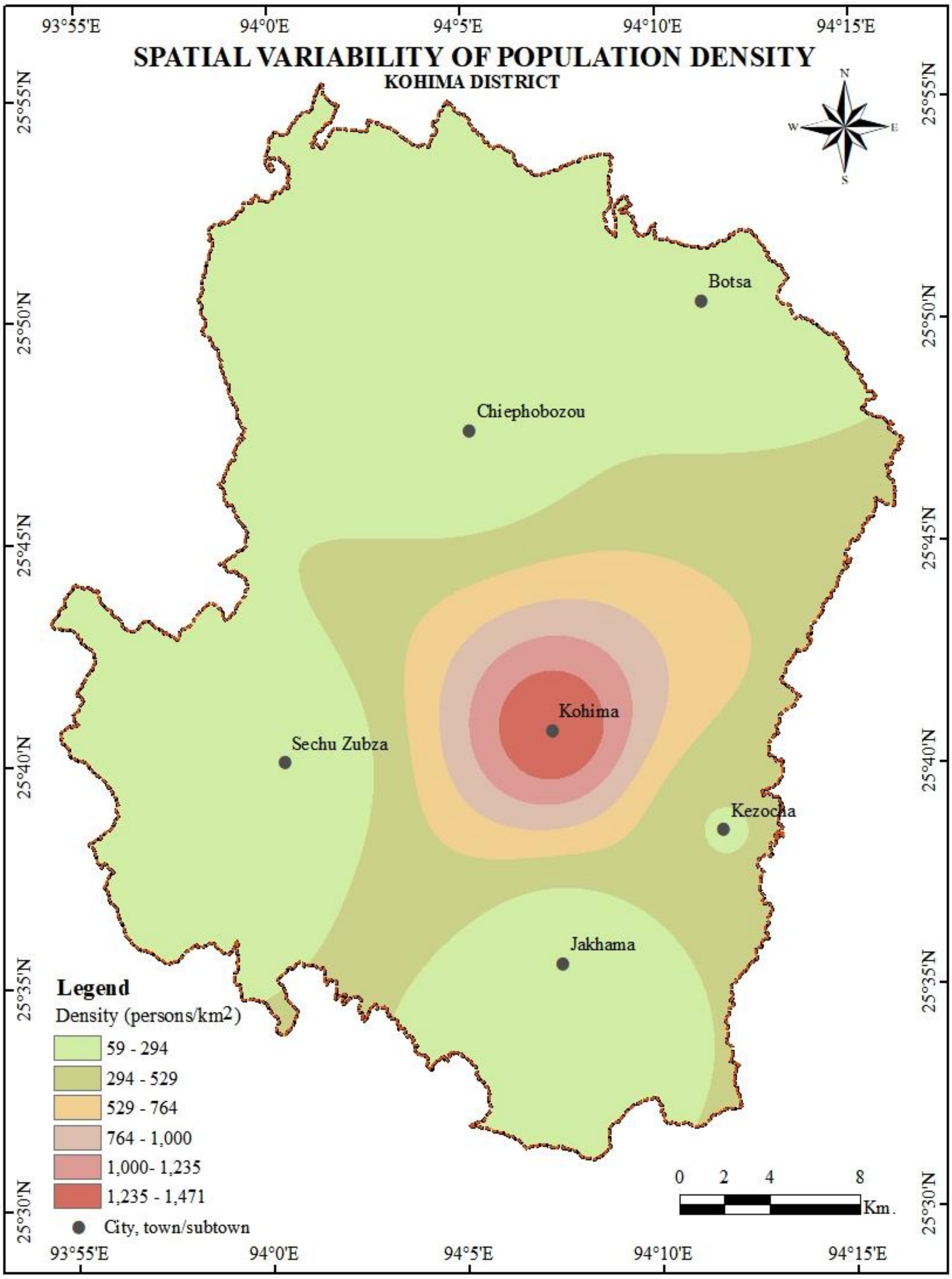


Figure 2.22: Spatial density of population of Kohima district, Nagaland. 2011.

2.2.3.2. Temporal variability of population: The objective is to analyze the population dynamics and temporal patterns of population change in the Kohima district by comparing the latest census data from 2011 with the previous census data from 2001. The data indicates that Tseminyu and Cheiphobozou have undergone a decline in population, whilst the other circles have witnessed an increase. Among them, Jakhama circle has shown the largest percentage of growth (Table 2.10 and Figure 2.23). The main reason for this is the transformation of the Jakhama circle into an institutional hub, with well-known colleges and schools in the surrounding area. Additionally, the increase in population and the availability of various amenities contribute to this phenomenon. The circle's excellent road connectivity to the main town of the district also plays a role in its popularity. Figure 2.24 illustrates the regional spatial variability of population increase between 2001 and 2011.

Table 2.10 : Decadal population variation of Circles, Kohima district, Nagaland, 2001-2011 (Source: District Census handbook Kohima, 2011).

Circles	2001	2011	% decadal variation
Chiephobozou	24333	19692	-19.07
Botsa	-	6695	0
Kezocha	12216	16467	34.8
Jakhama	23987	34056	41.98
Kohima sadar	91082	116870	28.31
Sechu zubza	14836	17369	17.07
Total	166454	211149	22.19

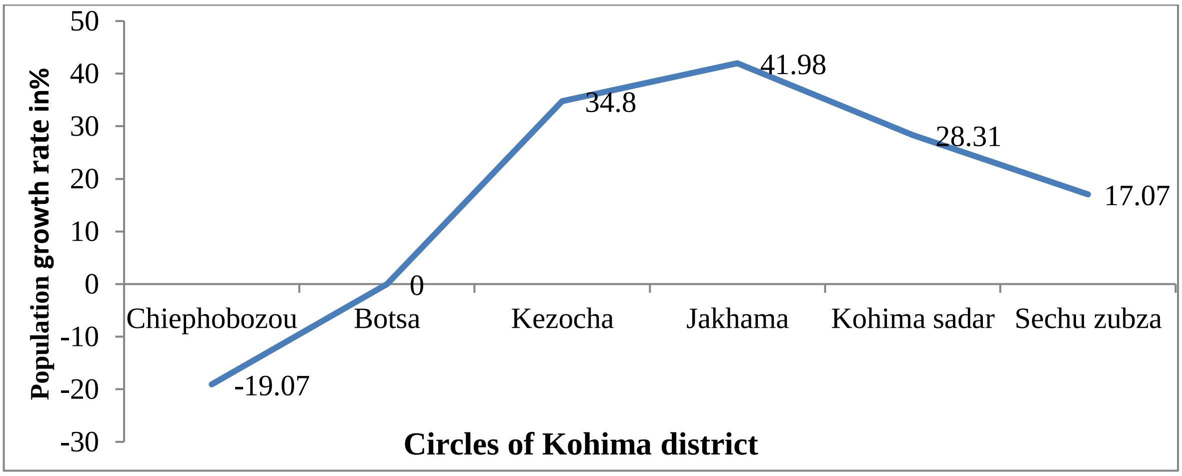


Figure 2.23: Circle wise decadal population variation of Kohima district, Nagaland, 2001-2011.

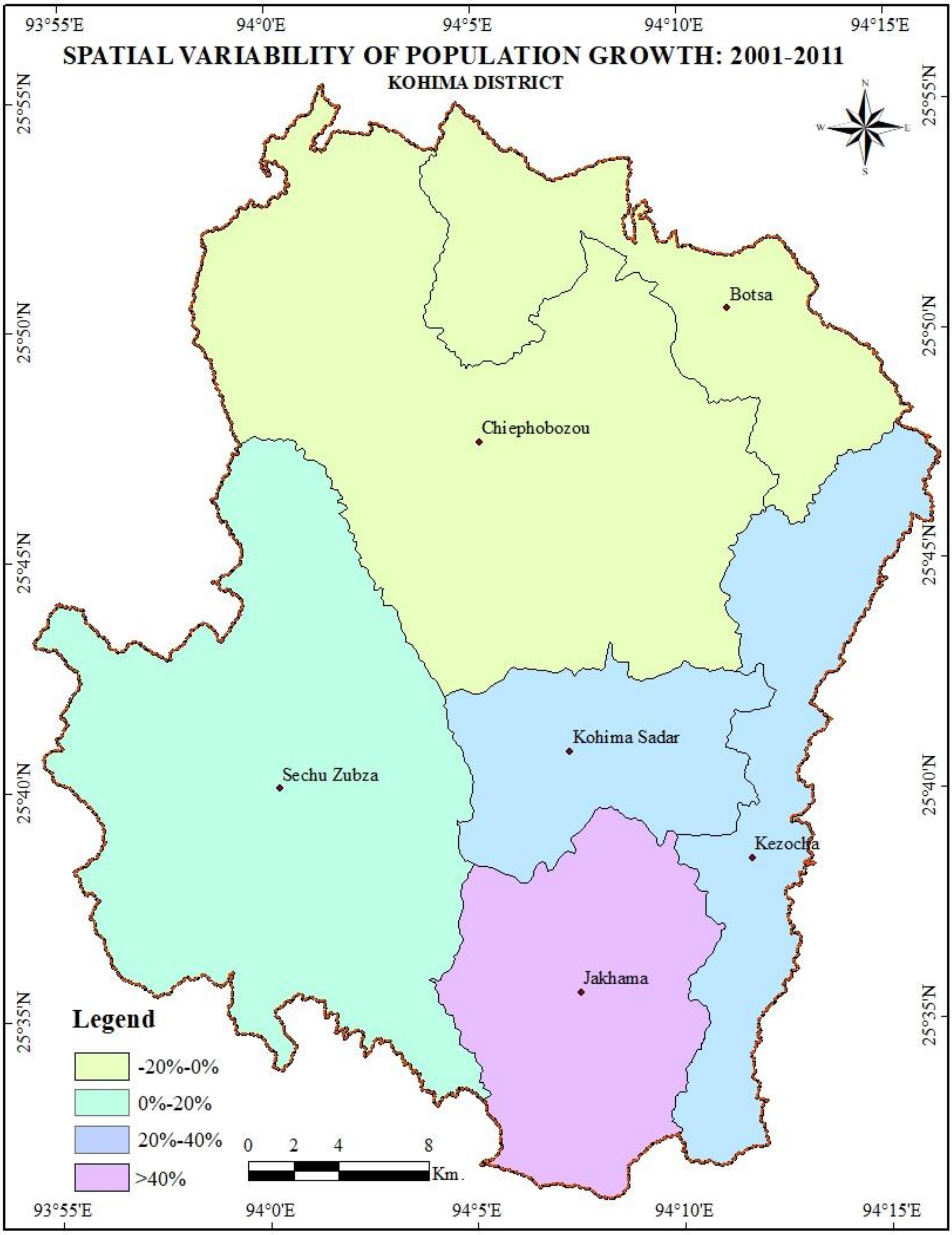


Figure 2.24: Spatial variability in population growth in Kohima district, Nagaland, 2001-2011.

2.2.3.3. Rural-urban composition of population: A study on rural-urban composition reveals that around 54% of the overall population resides in urban areas, specifically in Kohima city and its surrounding suburban regions. The remaining 46% of the population resides in the rural areas of five additional circles, namely Chiephobozou, Botsa, Kezocha, Jakhama, and Sechu Zubza (Table 2.11). It is evident that the majority of the population resides in the Kohima Sadar Circle, since individuals from rural regions are relocating to urban areas mostly owing to push and pull causes of migration in pursuit of an improved quality of life.

Table 2.11: Rural and urban compositoin of population in Kohima district, 2001-2011 (Source: District Census handbook Kohima, 2011).

Circles	Rural	Urban	Total
Chiephobozou	19692		19692
Botsa	6695		6695
Kezocha	16467		16467
Jakhama	34056		34056
Kohima sadar	2097	114773	116870
Sechu zubza	17369		17369
Total	**96376**	**114773**	**211149**
	46%	**54%**	**100%**

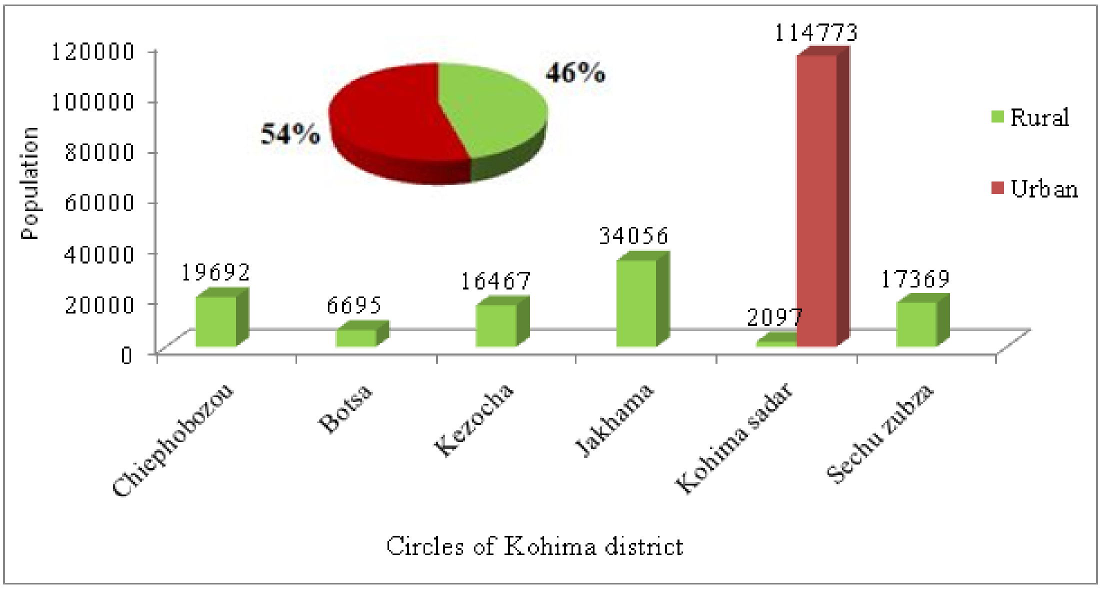


Figure 2.25: Rural and urban compositoin of population in Kohima district, Nagaland, 2001-2011.

2.2.3.4. Young child age population: The age range of early childhood (0-6 years) is considered one of the most critical, delicate, and susceptible segments of the population. This is a highly remarkable phase of growth and development in a child's existence. To ensure optimal levels of health, nutrition, education, safety, and other essential needs, governments, non-governmental organizations, and people conduct various programs based on census data. It is important to note that the demographic composition of children in the research region was studied based on the 2011 census data. The statistics indicates that around 12% (26389 individuals) of the entire population consists of children under the age of 6. The proportion fluctuates between a high of 17% in Botsa district and a low of 11% in Jakhama circles, as shown in Table 2.12.

Table 2.12: Young child age population in Kohima district, Nagaland (Source: District Census handbook Kohima, 2011).

Circles	Total Population	Child age population	% of total population	Density of Child population
Kohima Sadar	116870	14359	12	131
Jakhama	34056	3733	11	33
Chiephobozou	19692	2624	13	9
Sechu-Zubza	17369	2314	13	29
Kezocha	16467	2220	13	19
Botsa	6695	1137	17	4
Total	**211149**	**26387**	**12**	**26**

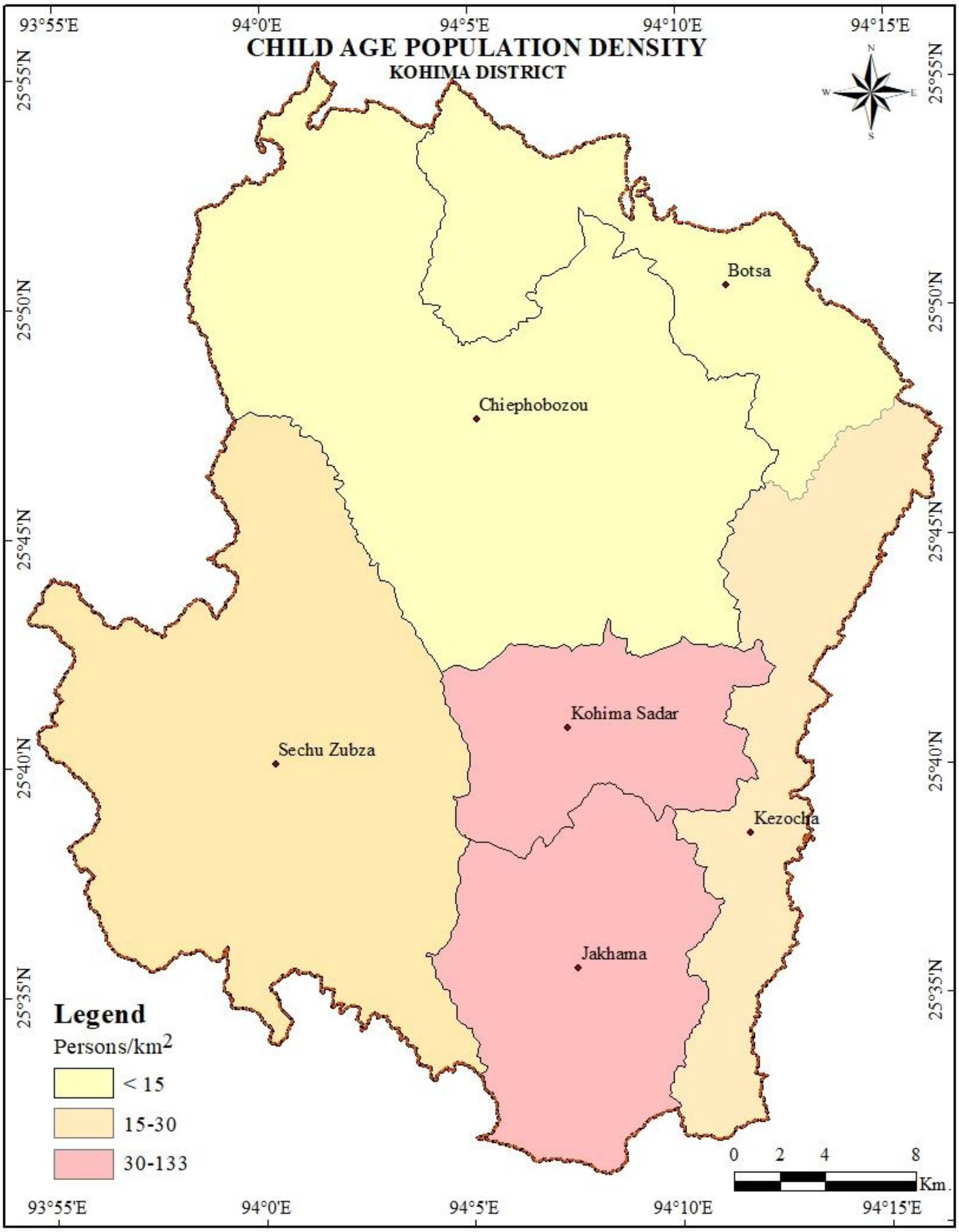


Figure 2.26: Young child age population in Kohima district, Nagaland.

2.2.3.5. Disabled population: Individuals with disabilities, regardless of their age, whether they are youngsters, young adults, or elderly, are especially susceptible and exposed to geomorphic dangers. Take note of this analysis of the geographic distribution of the handicapped population, which was conducted using census data from 2011. Based on the census statistics, the Kohima district has a total of 2697 handicapped individuals, which accounts for 1% of the overall population. These disabled individuals encompass many forms of disabilities, including visual, auditory, speech, mobility, and mental illnesses. Table 2.12 shows that the number of disabled individuals ranges from a high of 1169 people in Kezocha circle to a minimum of 181 people in Botsa circle. In Kohima sadar, Jakhama, Sechu-zubza circles, the corresponding figures are 197, 134, 329, and 687, respectively. Figure 2.27 illustrates the geographical dispersion of the disabled population in Kohima district, including its six administrative circles.

Table 2.13: Disabled population in Kohima district, Nagaland (Source: District Census handbook Kohima, 2011).

Circles	**Total population**	**Disabled population**	**% of total population**	**Disabled population density**
Kohima Sadar	19692	197	1	2
Jakhama	6695	134	2	1
Chiephobozou	16467	329	2	1
Sechu-Zubza	34056	687	2	9
Kezocha	116870	1169	1	10
Botsa	17369	181	1	1
Total	**211149**	**2697**	**1**	**3**

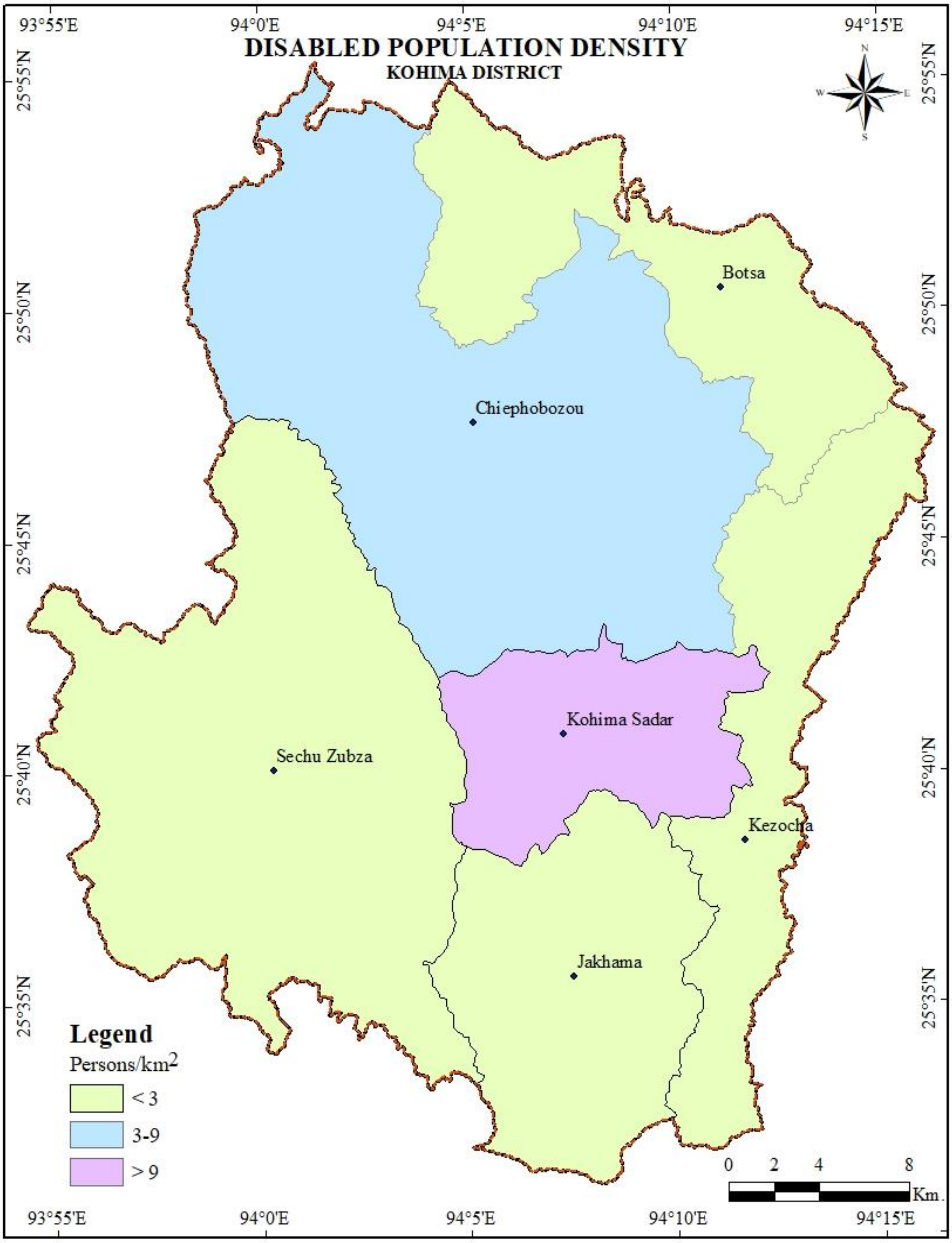


Figure 2.27: Spatial variability of disabled population in Kohima district, Nagaland.

2.2.3.6. Literacy: Out of the total population of the Kohima district only 85.23 % people are literates and educated. It has been observed that the male literacy level (88.69 %) is higher than the female literacy level (81.48%). The rate of literacy in the district varies at a minimum from 73.40 % in Kezocha circle to 89.94% in Kohima Sadar circle with an average literacy rate of 85.23% (Table 2.13 and Figure 2.28).

Table 2.14: Literacy rate by sex in sub-districts, 2011 (Source: District Census handbook Kohima, 2011).

Sub-Districts	**Literacy rates**		
	Male	**Female**	**Average**
Chiephobozou	86.52	76.18	81.67
Botsa	82.29	75.21	78.75
Kezocha	81.43	62.9	73.40
Jakhama	88.87	78.16	83.73
Kohima Sadar	92.18	87.5	89.94
Sechu- Zubza	87.28	78.59	83.47
District Kohima	**88.69**	**81.48**	**85.23**

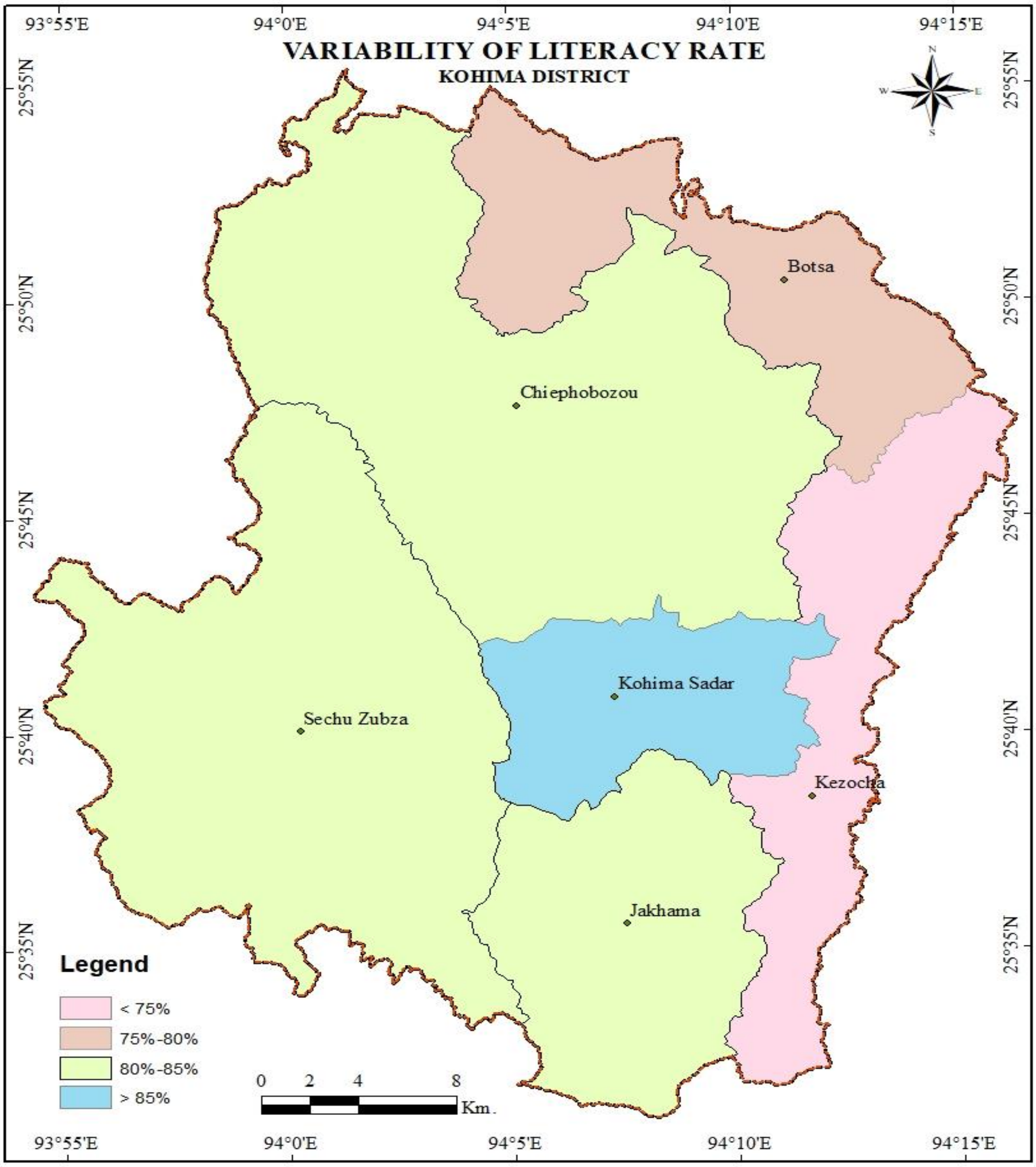


Figure 2.28: Spatial variability of literacy rate in Kohima district, Nagaland, 2011.

2.2.4. Settlements

Kohima is predominantly characterized by its mountainous and undulating terrain, with towns primarily located along the ridges of many hills. Kohima town, the capital of Nagaland, is primarily composed of administrative and commercial buildings, as well as residential areas. The town is organized in a clustered settlement, with a concentration of buildings and residents. The town is expanding towards the north due to the growing population and limited availability of land for construction. The distribution of settlements in the villages of Kohima district is more scattered compared to the town area. This is mostly due to the migration of people in pursuit of employment, education, and other opportunities, which creates a pattern of dispersion. Due to increasing congestion in the town area, institutional planning has begun considering the construction and establishment of educational institutions and associated amenities in the neighbouring village areas. These villages have significantly contributed to the economic growth of their respective areas. Regarding the resilience of settlements to geo-hazards, it is seen that many rural settlements are highly vulnerable. Similarly, in Kohima city and its surroundings, there are several families residing in settlements that were not constructed with geo-hazard resistance in mind.

Plate 2.1 (a)

Plate 2.1 (b)

Plate 2.1 (c)

Plate 2.1: (a), (b), (c) Photographs showing vulnerable settlements to geo-hazards in Kohima district, Nagaland.

2.2.5. Economy and occupational structure

Agriculture used to be the main economic activity of Nagaland, with around 70% of the population engaged in agricultural activities. However, as time passed and developments and the longing for more grew, the people of Nagaland have started to look into a wider perspective in the quest to make a living. According the census data 2011, out of the total population (211149) of the Kohima district 44 % (91879) fall in the category of working population and remaining 56% (119270) are non-workers (Table 2.14).

2.2.5.1. Working population: Out of the total workers, 38 % (79965) are main workers, 6 % (1194) are marginal workers (Table 2.14 and Fig. 2.30). Spatial distribution of occupational structure suggests that Jakhama circle constitutes maximum percentage of working population of its total population whereas Kohima Sadar has minimum percentage of working population of its total population (Table 2.14).

2.2.5.2. Non-working population: Out of the total population (211149) of Kohima 56% (119270) is dependent population which is considered as non-workers, 38 % (79965) are main workers, 6 % (1194) are marginal workers (Table 2.14 and Figure 2.31). Spatial distribution of such dependent population suggests that Kohima sadar circle has maximum percentage of working population of its total population whereas Jakhama circle has minimum percentage of dependent non-working population of its total population (Table 2.14).

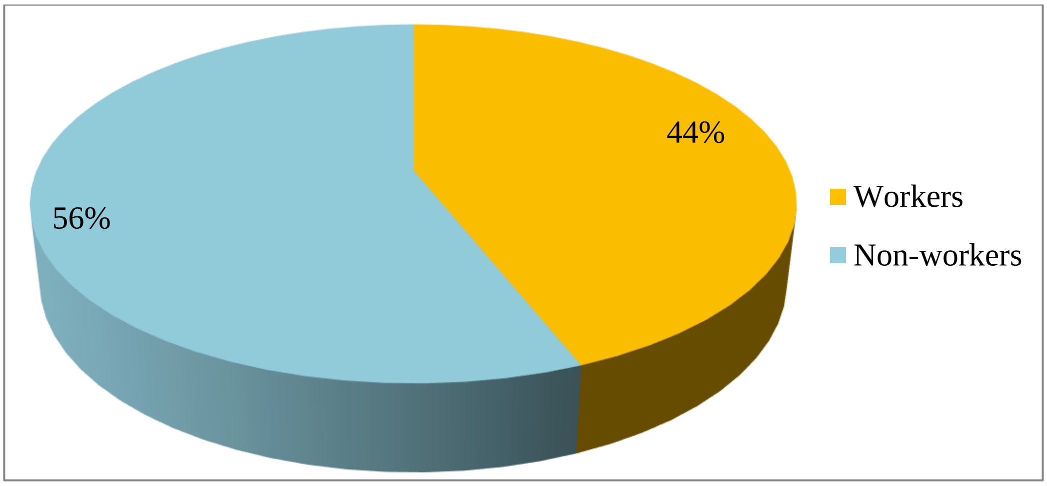


Figure 2.29: Occupational structure in Kohima district, Nagaland, 2011.

Table 2.15: Occupational structure of population in Kohima district, Nagaland (Source: District Census handbook Kohima, 2011).

Name of Sub-district	Total Population	Main Workers		Marginal Workers		Total Workers		Non-Workers	
		Number	%	Number	%	Number	%	Number	%
Chiephobozou	19692	8486	43	937	5	9423	48	10269	52
Botsa	6695	2833	42	600	9	3433	51	3262	49
Kezocha	16467	7572	46	1102	7	8674	53	7793	47
Jakhama	34056	14991	44	4168	12	19159	56	14897	44
Kohima Sadar	116870	38665	33	3656	3	42321	36	74549	64
Sechu-Zubza	17369	7418	43	1451	8	8869	51	8500	49
Total	**211149**	**79965**	**38**	**11914**	**6**	**91879**	**44**	**119270**	**56**

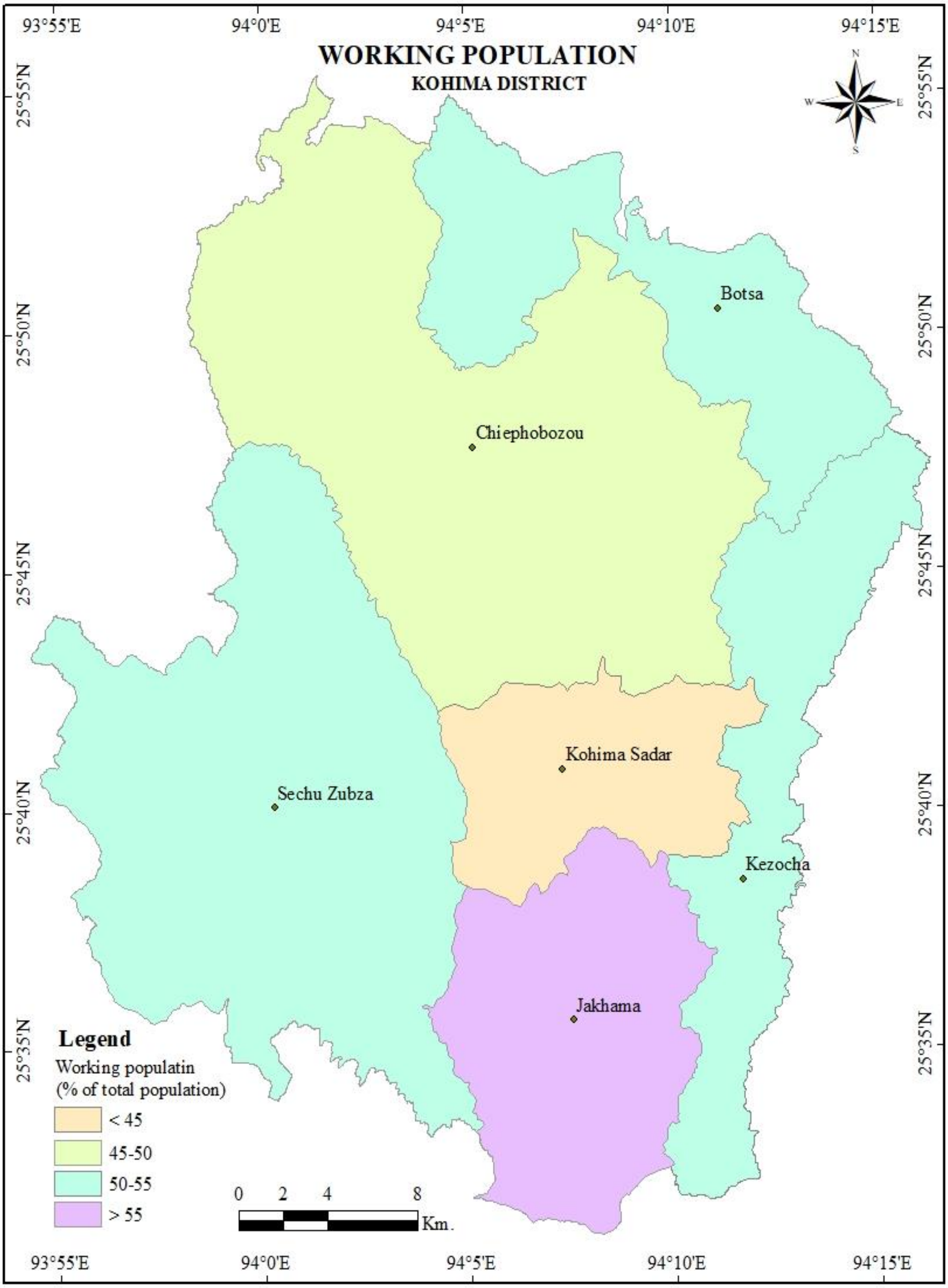


Figure 2.30: Spatial variability of working population in Kohima district, Nagaland, 2011.

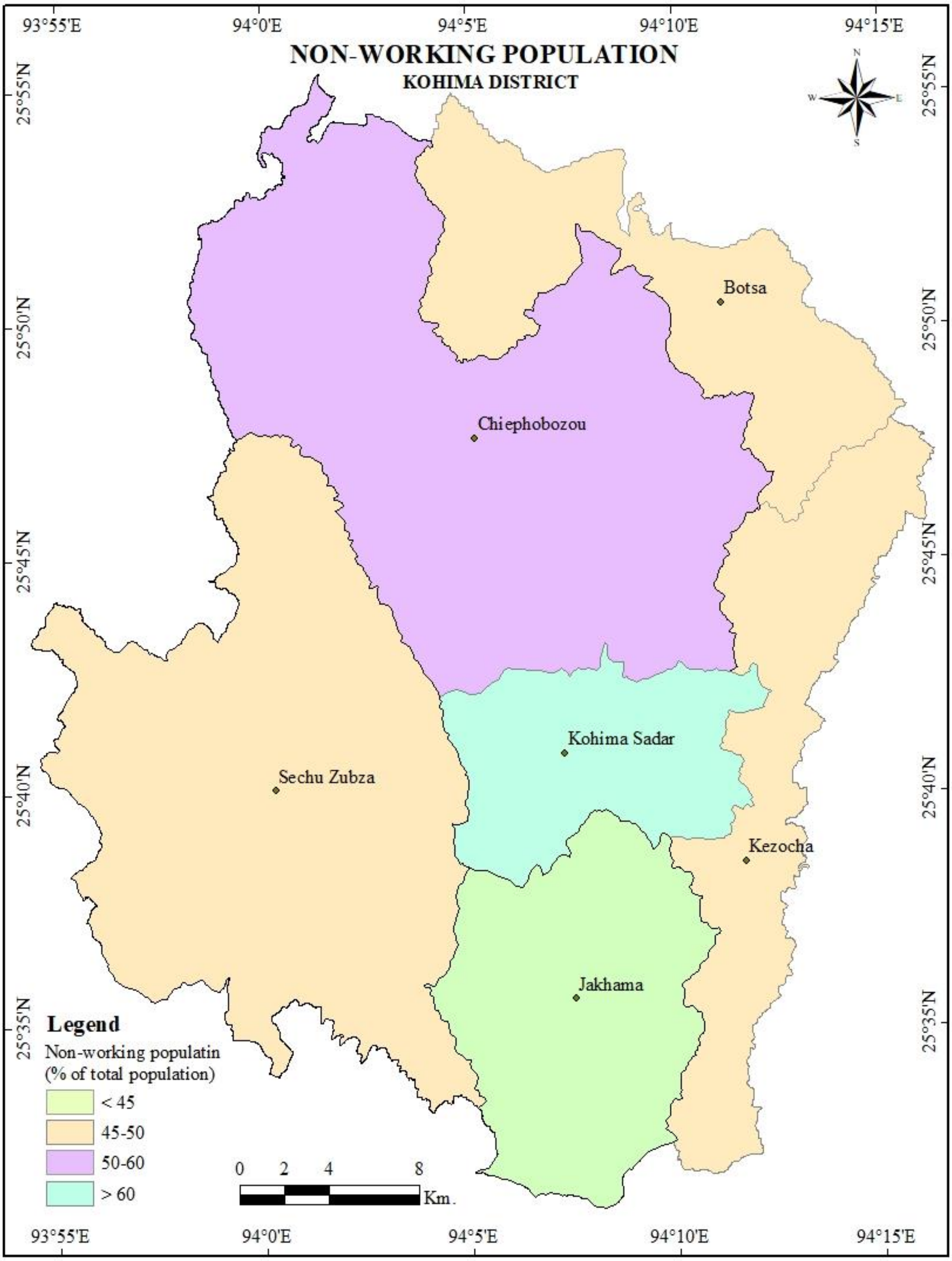


Figure 2.31: Spatial variability of non-working population in Kohima district, Nagaland, 2011.

References

Attri, S.D., Jyagi, A. (2010) Climate profile of India, Ministry of Earth Science, Indian Meteorological Department, Govt. of India

Banerjee, R. (2010). Seismic Hazard zonation of Kachchh region using remote sensing (RS) and Geographic Information System (GIS), Department of Geology, Faculty of Science, University of Pune

Bell, R., Fort, M., Gotz, J., Bernsteiner, H., Andermann, C., Etzlstorfer, J., Posch, E., Gurung, N. and Gurung, S. (2018). Major geomorphic events and natural hazards during monsoonal precipitation 2018 in the Kali Gandaki valley, Nepal, Himalaya. Elsevier

Bhattacharjee, C.C. (1991). The ophiolites of northeast India — a subduction zone ophiolite complex of the Indo-Burman orogenic belt, Tectonophysics, Volume 191, Issues 3–4, Pages 213-222, ISSN 0040-1951, https://doi.org/10.1016/0040-1951(91)90057-Y. (https://www.sciencedirect.com/science/article/pii/004019519190057Y)Bloom 2012

Directorate of Census Operations Nagaland (2011): District Census Handbook, Kohima

Directorate of Geology and Mining (1996): Feasibility studies for groundwater development in the hilly terrain in and around Kohima town, Nagaland

Directorate of Soil and Water Conservation, Kohima, Nagaland: Meteorological data

Ettwein, V., Maslin, M. (2011) Physical Geography: Fundamentals of the physical environment, University of London

Furkumzuk, C., (2011): Integrated Watershed management in the Kiliki watershed of Zunheboto hills, Nagaland. Ph.D Thesis

Gabler, R.E., Petersen, J. F., Trapasso, L. M., (2007): Essentials of Physical Geography, Eight edition, Thomas Higher education, 10 Davis Drive, Belmont, USA

Gabler, R.E., Petersen, J. F., Trapasso, L. M., and Sack, D. (2009) Physical Geography, 9thedition, Brooks/Cole, Cengage learning

Gares, P.A., Sherman, D.J., Nordstrom, K. (1994). Geomorphology and natural hazards. Geomorphology 10. Pg 1–18

Geological Survey of India, Ministry of Mines, New Delhi, India

Groves, R.M., Fowler, F.J. Jr., Couper, M.P., Tourangeau, R., Singer, E., Lepkowski, J.M. (2004). Survey methodology. Wiley, New York

Indian Meteorological Department, Ministry of Earth Sciences, Government of India

James, L.A., Harden, C.P., and Clague, J.J. (2013). Treatise on Geomorphology: Geomorphology of human disturbances, climate change and natural hazards. Vol.13. Pg 1-13

Karan, P.P. (1987). Bhutan: Development amid environmental and cultural preservation. Institute for the study of languages and culture of Asia and Africa

Lohe, S. (2014). Environmental management of degraded ecosystem in Phek district, Nagaland- A geomorphological approach. Ph.D. thesis

Lynn, P. (2008). The problem of nonresponse. In: deLeeuw E, Hox J, Dillman D (eds) The international handbook of survey methodology. Lawrence Erlbaum Associates, Mahwah, NJ, pp 35–55

Lynn, P. (2002). Sampling in human studies. In: Greenfield T (ed) Research methods for postgraduates, 2nd edn. Arnold, London, pp 195–202

Mathur, L.P., Evans, P. (1964). Oil in India: 2nd Int. Geol. Cong. New Delhi

Nagaland GIS and Remote Sensing Centre (NGISRSC), Kohima, Nagaland, 797001

Rawat, M.S. (2011) Environmental Geomorphology and watershed management- A study from Central Himalaya. Published and printed by Concept publishing company Pvt. Ltd Regd. Office: A/15-16, Commercial block, Mohan Garden, New Delhi-110059

Reynolds, S.J., Rohli, R. V., Johnson, J. K., Waylen, P.R., Francek, M. A. (2015). Exploring Physical Geography. The McGraw hill companies, Inc. pp. 1-693

Singh, S. (2019). Changing perspectives in Geomorphology. Journal of Indian Geomorphology, Volume 7

Sing, S. (2009). Environmental geography. Published by Prayag Pustak Bhawan 20-A, University Road, Allahabad

Srivastava, V., Nakhro, R., Pandey, N. (2013). Geometry of mesoscopic folds in the vicinity of Disang and Piphima thrust in Kohima district, Nagaland

Statistical handbook of Nagaland (2011). Directorate of Economics and Statistics, Government of Nagaland, Kohima

Strahler, A., (2013). Introducing physical geography. 6th edition. John wileys and Sons, Inc.pp 1-661

Strahler, A.N., Strahler, A.H., (1978). Modern Physical geography. John Wileys and Sons, Inc pp.1-532

Thingo, V. (1994). Terrain evaluation of Kohima District, Nagaland, with special reference to Geomorphology. PhD Thesis. Gauhati University

Thornbury, W.D. (1997). Principles of Geomorphology, New Age International (P) Limited Publishers

Chapter - 3

Geomorphic Hazards in Kohima District

Geomorphological hazards as previously discussed are significantly increasing in intensity and in the number of occurrences and this very scenario is attributed to a number of both natural and anthropogenic causes. The convergence of the Indian plate and the Eurasian plate along a tectonic border is characterized by frequent little earthquakes (with magnitudes below 4). These earthquakes are responsible for different geostructural hazards in the region, including landslides, land fissures, land creeping, and soil erosion. Intense monsoonal rain and degrading landuse practices are other two most important factors responsible for the other 3 geomorphic hazards discussed here- Landslide, Soil erosion and Flash Floods. Geodynamic forces exerted on tectonic plates result in the development of strains both at their boundaries and within their core. The pressures mentioned create a global field and directly impact the Earth's surface (Fairbridge, 1981). These processes have an impact on the physical structure and shape of the surface. Countries located in the Himalayan region have a historical record of experiencing highly destructive earthquakes with magnitudes above 7 Mw (Moment Magnitude), resulting in significant economic and human casualties. However, conversely, the majority of small-scale microearthquakes are not documented. Simultaneously, these phenomena pose a substantial risk to both human life and socioeconomic stability due to land creeping, land fissuring, land subsidence, landslide, and slope collapse within a certain geographical region (Rawat, 2003; Ader et al., 2012; Sapkota et al., 2013; Rawat & Pant, 2016). Recent instances of geostructural catastrophes include the Doda land subsidence in Jammu Kashmir (February 2023), the Joshimath land subsidence from April 2022 to January 2023, and the Karnprayag land subsidence in January 2022, all of which occurred in the Uttarakhand state of India. These are a few recent instances that have gained recognition from both traditional media and social media due to significant economic damages and the significance of the locations. Simultaneously, several locations in the Himalayan states have been seeing these little earthquakes and periodically voicing their worries (Sundariyal et al., 2023). The Northeastern region is extremely susceptible to erosion, landslides and flash floods due to its geo-environmental conditions. These conditions include a humid tropical to humid sub-temperate climate with an average rainfall of 1600-3200mm, the presence of young and easily erodible rock formations made up primarily of sandstones, siltstones, and shales, a fragmented reshaping geomorphology, and high erodibility of both surface and sub-surface soils. However, human activities have been exacerbating the susceptibility of the environment to geomorphic hazards by means of fast and uncontrolled urbanization, along with the construction of infrastructure in both urban and suburban regions.

3.1. Seismotectonic in Kohima District

Kohima is located in zone V of the seismic scale, which is the highest seismic zone according to the Bureau of Indian Standards (BIS, 2002) and the Global Seismic Hazard Assessment Programme (GSHAP, 2006). The spatial distribution of historical earthquake events in the northeastern region of India indicates that in the recent past, two significant earthquakes occurred. The first earthquake, with a magnitude of 8.7 Mw (Moment Magnitude), took place in 1897 in Assam at coordinates 26.0ºN and 90.7ºE. The second earthquake, measuring 8.6 Mw, occurred in 1950 in the Assam-Tibet region at coordinates 28.36ºN and 96.45ºE. These earthquakes caused severe damage to both the people and property in this area. On the other hand, this area has had several destructive earthquakes in the past, specifically in the years 1548, 1596, 1607, 1642, 1663, 1696–1714, 1869, 1882, and 1897 (Edward Gait, 1933). According to the local viewpoint of the Kohima area, a comprehensive record of 1102 earthquake occurrences has been documented during the past four decades (1982-2022) by CSIR-NEIST (2022). The earthquake occurrences are shown on top of the structural lineament and geological maps to create a seismotectonic map of the region (Figure 3.1).

3.1.1. Methodology

3.1.1.1. Geospatial database development: To develop the seismotectonic map, GIS and remote sensing techniques were used to collect primary data on the geoenvironmental characteristics of the terrain. This includes information on the drainage pattern, slope, relief using a digital elevation model, structural lineaments, geology, tectonic geomorphology, and subsurface geomorphology. The GIS maps underwent rigorous fieldwork verification and were ultimately approved for use as primary data. To do this crucial task, STRM and Google Earth satellite data were georeferenced and co-registered in a GIS environment using Survey of India topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000. The Seismotectonic atlas map of India (GSI 2000) was utilized during fieldwork to create a seismotectonic map of the research region (figure 3.1).

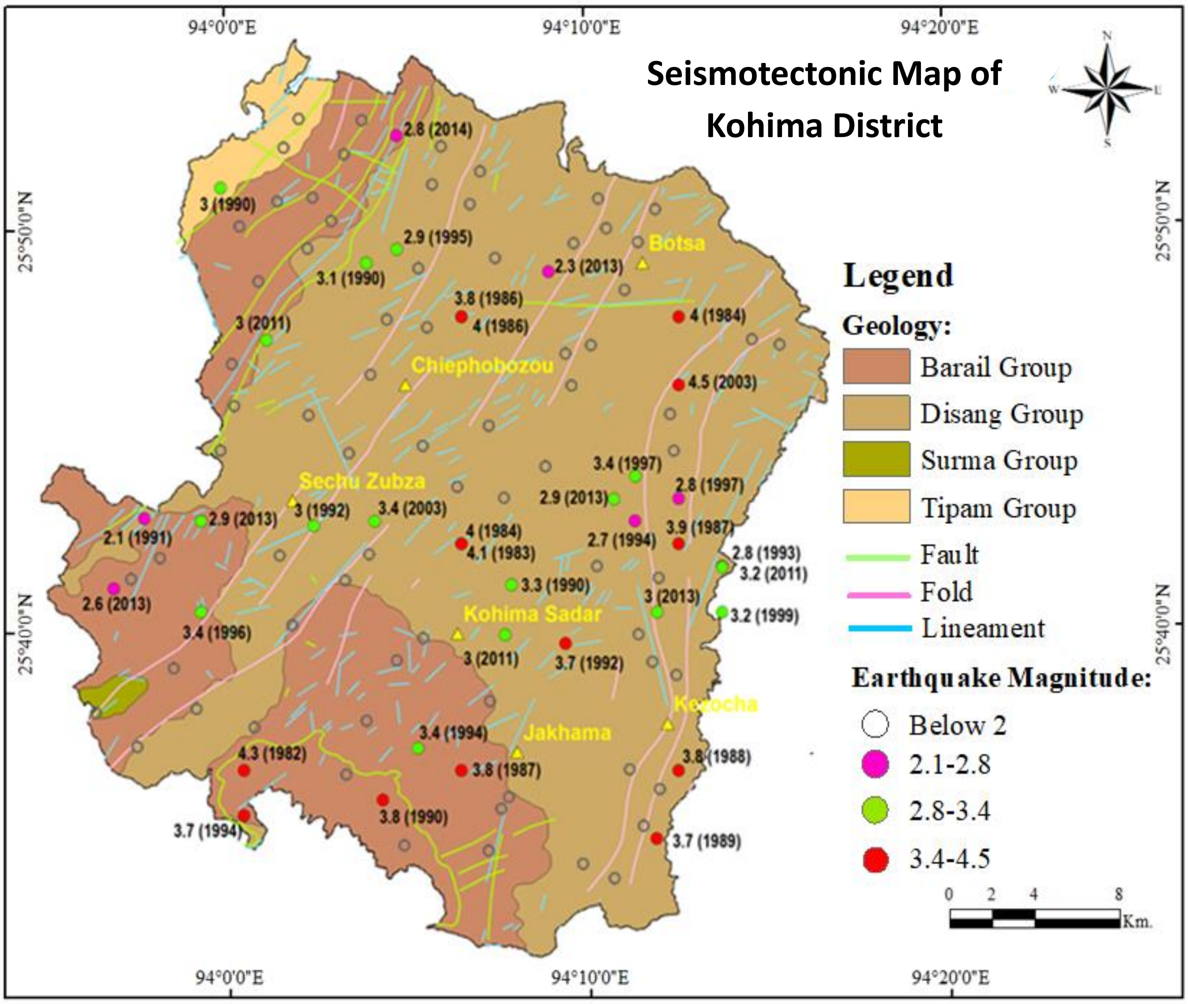


Figure 3.1: Seismotectonic map of Kohima district, Nagaland.

3.1.1.2. Seismic database compilation and homogenization: Earthquake data between the years 1762 and 2022 was gathered from many primary and secondary sources and then transformed into a Geographic Information System (GIS) environment. Primary sources consist of prominent international and national seismological agencies, such as the International Disaster Database (EM-DAT), the Indian Meteorological Department (IMD) in New Delhi, the International Seismological Centre (ISC), the United States Geological Survey (USGS), the Incorporated Research Institutions for Seismology (IRIS), the European-Mediterranean Seismological Centre (EMSC), and the National Oceanic and Atmospheric Administration (NOAA). The published study was also scrutinized to gather the necessary data and information. The earthquake data gathered was not uniformly measured, with some data recorded in surface magnitude unit (Ms), some in body magnitude unit (Mb), and some in moment magnitude unit (Mw). However, the data was not consistent in terms of seismic hazard assessment, namely regarding the reported magnitude of earthquakes. The homogenization procedure was conducted to convert the surface magnitude units (Ms), body magnitude units (Mb), and moment magnitude unit (Mw) into Mwg, using two equations proposed by Das et al. in 2019 and 2023:

Mw= (earthquake in Mw+10.7) *3/2=Log Mo i

Mwg=Log Mo/1.36-12.68 ii

3.1.1.3. Micro- Earthquake Hazard Zonation: The present study indicated that the Scalogram Modelling Approach (SMA) (Cruz, 1992) is the most suited method for conducting micro seismic hazard zonation. The geographical distribution of earthquake frequency and density maps is overlaid on geostructural, geological, geomorphological, and seismotectonic maps in order to calculate the microearthquake hazard index (MEHI). MEHI was specifically created for the research region using the modelling technique mentioned. To generate MEHI for the research region, a total of 7 significant seismic indicators, each with 28 classes, were converted into weight maps. Weightage was assigned to each class of the key seismic indicators, as shown in Table 3.2. The Scalogram model, as described by Cruz (1992) and Rawat et al. (2012), was utilized for micro earthquake hazard zonation in the research region, taking into account all the relevant factors.

MEHI (Score) = [X1 (An) + X2 (An) + X3 (An) + X4 (An) + X5 (An) + X6 (An)]
Where;

MEHI is Micro Earthquake Hazard Index,

X1, X2, X3, X4, X5 X6 and X7 are major factors: slope, geology, geostructural lineaments types, lineament density, geomorphology, earthquake density and past earthquake magnitudes (Table 3.2).

'An' is the total weight score (such as 1+2+3+4=10) of excising sub-factors or classes (respectively A1, A2, A3, and A4) of a particular major factor (Table 3.2),

To accomplish this, the Analytical Hierarchy Process (AHP) developed by Saaty (1980) was utilized to create a geographical distribution map of micro earthquake hazard susceptibility. This was achieved by doing an overlay operation in the ArcMap GIS program. The overlay process aggregated the weightage values, which varied from 7 to 28, throughout the whole research region. These values were then divided into four groups: below 8, 8-16, 16-24, and above 24. These classes indicate the zones of low, moderate, high, and extremely high hazard zones for micro earthquakes.

Table 3.1: Earthquake database of Kohima district for the last 40 years (1982-2022)

Source: CSIR-NEIST, 2022.

Earthquake Magnitude		Type of Earthquake	Number of Events		In %
in Mw	**In Mwg**		**1982-2022**	**Annual Rate**	
<2	<1.33	Micro	10	3	0.91
2-3	1.33-2.43	Micro	219	55	19.86
3-4	2.43-3.53	Micro	609	152	55.25
4-5	3.53-4.64	Light	249	62	22.60
5-6	4.64-5.74	Moderate	13	3	1.14
6-7	5.74-6.84	High	3	1	0.27
		Total	**1102**	**276**	**100.00**

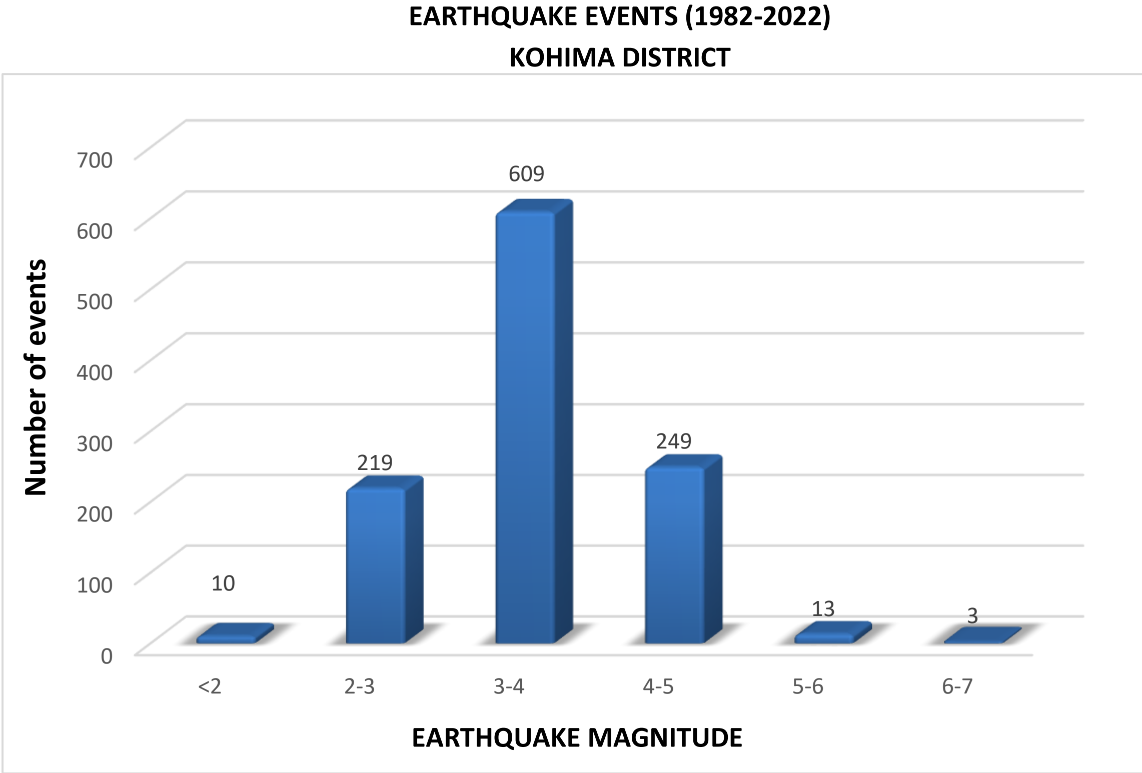


Figure 3.2: Earthquake events occurred during the last four decades 1982-2022, in Kohima district, Nagaland.

Table 3.2: Total 7 main factors (X) and their 28 sub-factors (A) have been considered as causative factors of micro earthquake hazard.

	Geo-environmental Factors (Main factors): X							Susceptibility to low magnitude Earthquake Hazards	Assigned Weightage
	Slope classes	Geology	Types of structural lineaments	Density of structural lineaments (km/km^2)	Geomorphology	Earthquake Density ($no/10km^2$)	Past earthquake magnitude (Mw/Mwg)		
	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)		
A1	Below 4°	**Carbonaceous shales** with siltstones	Fold aligned hills	<0.80	Lower-level dissected hills, alluvial piedmont zone	Below 4	Below 3 Mw (1.33-2.43 Mwg)	Low	1
A2	4°-8°	Grained **sandstone,** silty-shale and carbonaceous shale	Joint/Fractures zones	0.80-1.20	Structural/dissected mid-level hills	4-8	3-4 Mw (2.43-3.53Mwg)	Moderate	2
A3	08°-12°	Grained **sandstone,** silty-shale and carbonaceous shale	Shear zone	1.20-1.60	Structural/dissected moderate-high level hills	8-12	4-5 Mw (3.53-4.64 Mwg)	High	3
A4	12°-16°	Sandstone rock	Fault/thrust aligned valley	1.60-2.00	Structural/dissected high level	Above 12	Above 5 (Above 4.64 Mwg)	Very High	4

Based on seismotectonic data, there were a total of 10 earthquakes with a magnitude between 1-2 Mw (<1.33 Mwg), 219 earthquakes with a magnitude between 2-3 Mw (1.33-2.43 Mwg), 609 earthquakes with a magnitude between 3-4 Mw (2.43-3.53 Mwg), 249 earthquakes with a magnitude between 4-5 Mw (3.53-4.64 Mwg), 13 earthquakes with a magnitude between 5-6 Mw (4.64-5.74 Mwg), and three earthquakes with a magnitude between 6-7 Mw (5.74-6.84 Mwg) during the specified period (Table 3.1 and Figure 3.2). The investigation of these 1102 earthquake occurrences indicates that they are linked to active thrust faults located between two large geological sections (Figure 3.1). The seismic characteristics of these 1102 earthquake occurrences show that 76% of the total events are micro earthquakes, which have a magnitude below 4Mw or 3.53Mwg. The remaining 24% of earthquakes fall into the moderate to high magnitude range, with magnitudes ranging from 4-7 Mw or 3.53-6.84 Mwg.

Statistical analysis of seismic data from 1982 to 2022, shows that an average of 27 earthquakes occur yearly in the region. Out of these, 76% (20 occurrences) are microearthquakes with magnitudes below 4. The presence of low-magnitude earthquakes in the region suggests that the area's geological structure is extremely active, as these earthquakes are attributed to local seismotectonic activity. Fieldwork observations indicate that the region experiences a high prevalence of geostructural hazards, including land creeping, land fissuring, land subsidence, landslide, and slope failure. These hazards are primarily caused by microseismic activities along regional and local geostructural thrusts, faults, and other lineaments. It is crucial to handle this ongoing environmental hazard in order to prevent or minimize the socioeconomic losses associated with any geophysical event.

Evidence suggests that the Kohima area is prone to experiencing large-scale earthquakes with significant regional effects, as well as regular small-scale earthquakes that indicate ongoing tectonic activity. The occurrence of microearthquakes or neotectonic events in this area results in many geostructural hazards, including creeping, land fissuring, land subsidence, landslides, and slope failures. These hazards can lead to the loss of both property and life (Bhandari et.al., 1975). Seismic activity, while natural, are beyond our control and their timing cannot be accurately predicted. Nevertheless, we may alleviate the negative effects or drawbacks by promoting community consciousness and implementing appropriate developmental strategies, be it at the individual, communal, or governmental level. Nevertheless, the issue at hand is the feasibility of the task without the provision of a microearthquake danger zonation map for the specific location. In light of this, the current study presents a microearthquake hazard zone map for the Kohima district. This map was created by conducting a thorough geospatial analysis of the historical database of earthquake events and overlaying it with seismotectonic, geostructural lineaments, geology, geomorphology, and terrain characteristics map of the area using the Scalogram Modelling Approach (Cruz, 1992) (Table 3.2). The microearthquake danger zone map of Kohima delineates four distinct zones: the severe hazard zone, the very high hazard zone, the high hazard zone, and the moderate hazard zone (Figure 3.4).

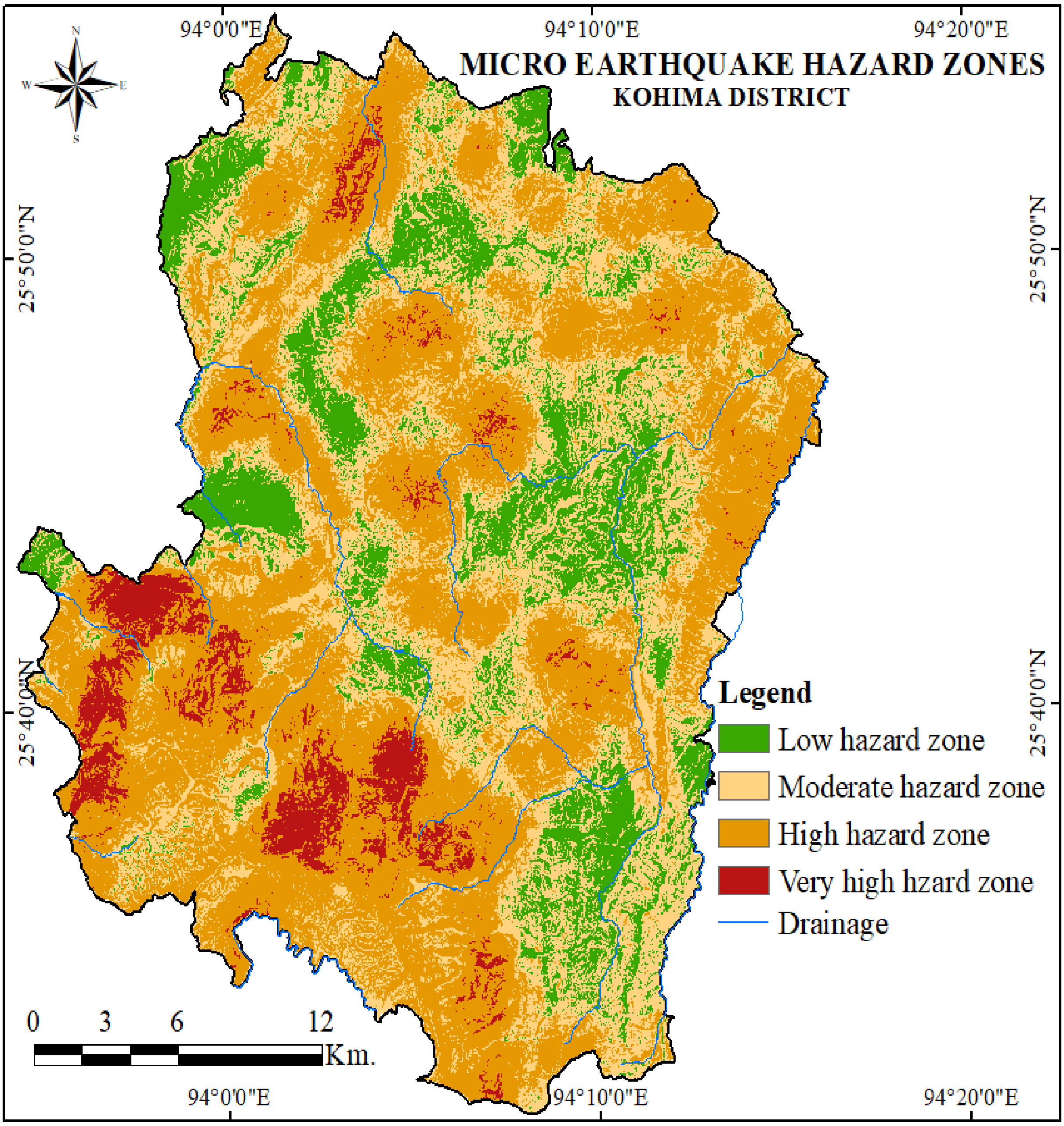


Figure 3.3: Micro earthquake hazard zonation of the Kohima district, Nagaland.

Table 3.3: Spatial variability of Microearthquake hazard zones in Kohima district, Nagaland.

Hazard Zones	Accumulate Weight value	Area	
		Km^2	%
Low Hazard	Below 8	137.05	14
Moderate Hazard	8-16	156.63	16
High Hazard	16-24	558.01	57
Very High Hazard	Above 24	127.26	13
	Total	**978.96**	**100**

3.1.2. Micro-earthquake Hazard Zonation in Kohima District

Low hazard zone of microearthquake: The low hazard zone of microearthquake is characterized by areas that experience 1-4 seismic events per 10 km^2 grid. These areas have a moderately stressed geoenvironmental setup, which includes more than 8-12 seismic events per 10 km^2, regional geological faults, lineament density below 0.80 km/ km^2, steep slopes below 15°, lower-level dissected hills, and an alluvial piedmont zone composed of black carbonaceous shales with siltstones and sandstones. Approximately 14% (137.05 km^2) of the entire region, which has a total size of 978.96 km^2, falls inside the low hazard zone as seen in Table 3.3 and Figure 3.3.

Moderate hazard zone of microearthquake: Zone of moderate seismic activity falls in areas with a density of 4-8 seismic events per 10 km^2 grid, along with a complex geoenvironmental setup (including more than 8-12 seismic events per 10 km2, regional geological faults, lineament density of 0.80-1.20 km/ km^2, steep slopes ranging from 15°-25°, and structural/dissected mid-level hills composed of grained sandstone, silty-shale, and carbonaceous shale) are classified as being in the moderate hazard zone for microearthquakes. The region has a total size of 978.96 km^2, with approximately 16% (156.63 km^2) being into the moderate danger zone, as seen in Table 3.3 and Figure 3.3.

High hazard zone of microearthquake: The high hazard zone of microearthquakes is characterized by areas that experience 8-12 seismic events per 10 km^2 grid. These areas have a very high stressed geoenvironmental setup, which includes a combination of factors such as the presence of regional geological faults, a lineament density of 1.20-1.60 km/ km^2, steep slopes ranging from 25°-35°, and the presence of structural/dissected moderate-high level hills composed of grained sandstone, silty-shale, and carbonaceous shale. These areas are considered high hazard zones for microearthquakes due to the continuous neotectonic activities that occur in these regions. Approximately 57% (558.01 $km^2$of the region's total area (978.96 km^2) is inside the severe hazard zone. (Table 3.3 and Figure 3.3).

Very high hazard zone of microearthquake: The areas with the most stressed geoenvironmental setup, including a regional geostructural thrust, lineament density of 1.60-2.00 km/ km^2, very steep slopes above 35°, and structural/dissected high-level hills made of sandstone rock, experience a high frequency of microearthquakes. These areas, which account for more than 12 seismic events per 10 km^2 grid, are classified as a very high hazard zone for microearthquakes due to the continuous neotectonic activities occurring there. Of the whole land area of Kohima, which is 978.96 km^2, 13% or 127.26 km^2 is classified as a very hazardous zone according to Table 3.3 and Figure 3.3.

Plate 3.1: Aerial view of Kohima city showing unplanned urbanization over steep unstable slope along tectonically active lineaments (Above) as evident by number of landslides, debris fall, creeping, land subsidence events continually taking place in such zones (Lower left and right images).

3.2. Soil Erosion Vulnerability of Kohima District:

Erosion is a significant geomorphic hazard in sub-tropical climatic environments worldwide, especially in the eastern Himalayas. This has been highlighted by Rawat and Pant in their studies conducted in 2014, 2016, and 2017, as well as by Gupta in 2023. The phenomenon has a significant impact on both the natural environment and the agriculture-centric rural economy. It leads to the acceleration of mass movement, landslides, removal of vegetation cover, and siltation of reservoirs, affecting the natural environment. Additionally, it causes the loss of the topmost fertile soil layer, resulting in a decline in crop yield, which directly affects the agriculture-centric rural economy. (Rawat and Rawat 1994, Rawat and Pant 2016, Gupta 2018, 2021). Erosion rates are influenced by various geophysical factors, including geology, structural lineaments, soil erodibility, relief pattern, slope gradient, and drainage morphometry. Hydro-meteorological factors such as temperature, rainfall, evaporation, surface percolation, and runoff also play a role. Additionally, anthropogenic factors such as vegetation cover, land use pattern, excavation, unscientific agricultural practices, community awareness level, and conservation support practices contribute to erosion rates. (Abdo and Salloum 2017; Sharma and Singh 2017; Rawat 2003, 2011, 2012, 2017). The erosion rates vary across different locations due to variations in geo-ecological systems. Desert ecosystems, without sufficient vegetation, experience erosion at significantly greater rates compared to humid ecosystems with dense evergreen plant cover (Miller and Donahue 1990; Rawat et al., 2011, 2011a, Rawat, 2013, 2014). Deforestation refers to the process of removing plant cover, which exposes the soil to erosive forces like water and wind. This leads to the loss of the top layer of soil, negatively impacting soil fertility (Rawat et al., 2012, 2012a, 2012b). Regarded as a perilous geomorphic hazard, some researchers have labelled it as the 'creeping death of the soil' (Rama Rao 1962; Tripathi and Singh 1993; Angima et al. 2003; Sharma 2010). Pimentel et al. (1995) and El-Swaify (1997) have said in their research that Asia is among the regions with the highest susceptibility to soil erosion, with a soil erosion rate of 74 tons per acre per year (SE = 74 t/ac/year).

The northeastern area of India is geophysically characterized by a rough and undulating landscape mostly made up of highly erodible sandstone lithology. Furthermore, throughout the area, unscientific traditional shifting (Jhum) agricultural practices have been hastening soil sheet erosion, resulting in negative ecological consequences such as shrinking habitats, escalating conflicts between humans and wildlife, loss of biodiversity, degradation of soil quality, and reduced crop yield. These practices also have hydrological impacts, including the drying up of water springs, streams, and watersheds during the dry season, as well as an increase in the frequency of extreme flood events during the rainy season (Rawat 2013, 2013a). As a result, it has led to a rise in unproductive regions, a shift in livelihoods, and the migration of people to other locations. This has had an influence on the socio-economic structure of the rural population (Rawat and Haigh 1998, Rawat et al. 1995, 1999, 2000). Consequently, it is crucial to locate all areas affected by erosion in order to promptly address erosion-related geomorphic hazards such as mass movement, landslides, and the loss of extensive vegetation cover, including forests. This will allow for the implementation of appropriate biological and mechanical measures to mitigate erosion in a timely manner. This study presents a comprehensive analysis of the environmental issue in Kohima district, Nagaland (India) using the Revised Universal Soil Loss Equation (RUSLE) model and GIS technologies. RUSLE, established by Wischmeier and Smith in 1978, is a highly utilized experimental model for assessing erosion rates. The use of geospatial technology, such as DEM, GIS, and remote sensing, allows for the input of spatial data into the RUSLE model. This enables the model to be effectively applied and accurately predict erosion rates in various study areas, such as watersheds, river basins, or large regional landscapes. This approach has been supported by studies conducted by Renard et al. (1997), Youe-Qing et al. (2008), and Kouli et al. (2009). The model was originally introduced as the Universal Soil Loss Equation (Wischmeier and Smith, 1978). However, recent research has referred to it as the Revised Universal Soil Loss Equation (RUSLE) model. This revision involves integrating modern geospatial technology and advocating for the large-scale application of the model for erosion hazard assessment (Prasannakumar et al., 2012; Demirci and Karaburum, 2012; Pradeep et al., 2015; Gelagy and Minale, 2016; Ganasri and Ramesh, 2016). Kohima is both a district and the capital city of the Northeastern Indian state of Nagaland. The region is extremely susceptible to soil erosion and rapid erosion-induced geomorphic hazards, such as mass movement, landslides, and slope failure. This vulnerability is due to the rugged and steep terrain, active tectonic activity, fragmented young geology, dynamic reshaping of the landforms, and the high density of the drainage network. It is crucial to examine regions impacted by erosion in order to adopt necessary actions to prevent increased erosion-induced geomorphic risks.

3.2.1 Methodology

3.2.1.1. Geo-environmental GIS modelling

The Geo-environmental GIS module offers spatial and attribute data on geophysical, hydro-meteorological, and ecological aspects. Geospatial techniques were used to create thematic GIS maps of various geophysical parameters, including geology, geomorphic landforms, topographic relief pattern, surface slope gradient, drainage morphometry, and soil characteristics. These maps were based on fieldwork and laboratory analysis. Additionally, hydro-meteorological parameters such as rainfall, runoff, and evaporation loss, as well as ecological parameters like climate, vegetation cover, and land use pattern, were also included in the analysis. In order to conduct geospatial analysis, Google Earth satellite images and Survey of India topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000 are utilized to create geological, tectonic, geomorphological, and soil distribution maps. The USGS-Landsat satellite imagery, which has a spatial resolution of 30m, was utilized to map land use patterns and vegetation covers, among other things. The NASA-STRM satellite imagery, which had a spatial resolution of 30, was utilized to analyze several aspects of the terrain, including relief, slope, watershed boundaries, drainage patterns, drainage order, drainage density, drainage frequency, water flow direction, and flow accumulation. These analyses were conducted using a digital elevation model. Rainfall data was collected monthly for a span of thirty years (1991-2022) from twelve locations at various elevations in the study area. Among these locations, eight were chosen to represent rainfall data recorded using web GIS technology by NASA Power Data Access Viewer (NASA-DAV: https://power.larc.nasa.gov/data-access-viewer/). Out of the total, four of them are terrestrial meteorological stations, managed by the Indian Meteorological Department (IMD) and the soil and water conservation department of Nagaland state government, with two stations each.

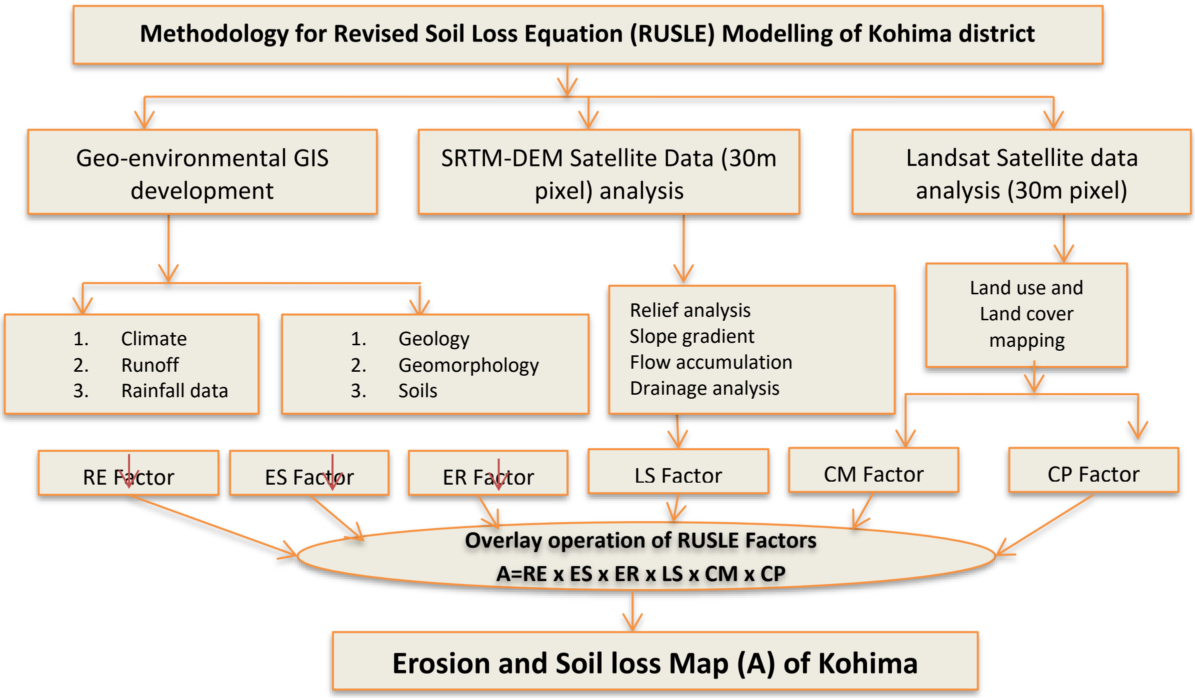


Figure 3.4. Methodology for Revised Soil Loss Equation (RUSLE) Modelling of Kohima district, Nagaland

3.2.1.2. Erosion hazard modelling

The geospatial technology-based Revised Universal Soil Loss Equation (RUSLE) model test was followed to carry out an erosion hazard study of the study area (USDA 1993). To carry out the average rate of erosion and soil loss, the RUSLE model requires integration of the erosion-controlling factors using the following equation:

$$A = RE \times ES \times ER \times LS \times CM \times CP$$

where A = Soil loss

RE = Rainfall runoff erosivity factor

ES = Erodibility of soil factor

ER = Erodibility of bedrock factor

L = Slope length factor

S = Steepness factor

CM = Cover and management factor

CP = Conservation practices factor

Selected factors were integrated with RUSLE in the GIS environment to get the soil erosion rate. Methods to analyze all these erosion-controlling factors are discussed below.

i. **Rainfall runoff Erosivity (RE) factor:** Rainfall-runoff erosivity is considered to be a key factor of the USLE model to estimate soil erosion. The RE-factor of USLE indicates the possible potential of a rainstorm incident to soil erosion. In the present study, the RE-factor is analyzed using total storm energy and its maximum 30-min intensity following Wischmeier and Smith (1978). Mean annual rainfall data for 30 years was used to estimate RE-factor following Choudhury and Nayak (2003):

$$R = 79 + 0.363 \times Xa$$

where RE is the Rainfall-runoff erosivity, and Xa is the Average annual rainfall (mm).

ii. **Erodibility of Soil (ES) factor:** ES expresses the resistance power of top surface soil against the rainstorm event, which depends on geo-chemical properties of soil such as dispersal of grain mass, organic matter and soil structure and absorbency (Wischmeier and Smith 1978). Based on the geological and pedological maps of the study area, ESR values of existing soil and rock types have been estimated from the nomogram (Wischmeier and Smith 1978) of RUSLE. The ES factor map of the study area has been prepared by plotting the ES/R values of each map unit.

iii. **Erodibility of Rock (ER) factor:** ER expresses residence power of bedrock (R) against the rainstorm event, which depends on geo-chemical properties of rock, such as dispersal of grain mass, organic matter and structure and absorbency (Wischmeier and Smith 1978). Based on the geological maps of the study area, ER values of existing rock types have been estimated from the nomogram (Wischmeier and Smith 1978) of RUSLE. The ER factor map of the study area has been prepared by plotting the ER values of each map unit.

iv. **Slope Steepness and Length (LS) factor:** LS factor combines two sub-factors which are length (L) of slope and steepness or slope gradient (S) of slope. The slope length factor represents the combined effect of steepness and length of slope on soil loss rate in a region. The higher the LS factor, the higher the vulnerability to soil loss. LS factor was determined using SRTM DEM data following Moore and Burch (1986).

$$LS = \text{Flow accumulation} \times \frac{\text{Cell size}^{0.4}}{22.13} \times \sin \frac{\text{Slope}^{1.3}}{0.0896}$$

Where, LS is the length and steepness factor of the slope respectively, cell size is the pixel value of a single grid cell which also reflects the spatial resolution of the DEM satellite image and sin is the slope degree value in the Sin table.

v. **Cover Management (CM) factor:** In general, it is a type of vegetation cover, which influences the rate of soil erosion as vegetal cover does not allow the rainstorm to interact directly with the top surface layer of soil and thereby averts the soil erosion. CM factor is expressed as the ratio of soil loss among different types of existing vegetation cover in the study area. The CM value ranges between 0 and 1 which was calculated using the following formula (Van der Knijff et al. 1999).

$$CM = \exp -\propto \frac{NDVI}{(\beta - NDVI)}$$

Where α and β are the parameters that determine the shape of the NDVI-C curve. α value of 2 and β value of 1 was taken (Van der Knifjj et al. 1999).

vi. **Conservation Practice (CP) factor:** The CP factor signifies the various land use and cover patterns within a certain region. This factor regulates soil erosion by altering the flow pattern, slope, or direction of runoff and by decreasing the amount and speed of runoff (Renard and Foster 1983). The study area was analysed using Landsat satellite imagery with a spatial resolution of 30m. The imagery was classified into five major types of land use/cover patterns: water bodies, dense forest area, degraded open forest, built-up land, and agriculture land. This classification was done using a supervised classification method. The resulting classification was then reclassified based on their CP values, as suggested in the USDA Handbook (1981) list.

3.2.1.2.1. RUSLE model test

Rainfall-runoff Erosivity Factor (RE): The average annual rainfall erosivity factor (RE) for the selected last three decades period (1991–2021) ranges between 648.12–1294.15 MJ mm/ha/h/year across the Kohima district (Figure 3.5 a). The higher values of rainfall erosivity (1000-1294.15 MJ mm/ha/h/year) are found in the southern part of the region having elevation above 1400m from mean sea level and the northern part, having lower elevation below 800m from mean sea level has lower values of rainfall erosivity (648-800 MJ mm/ha/h/year) whereas the mid-altitude area has a moderate rainfall erosivity between 800-1000 MJ mm/ha/h/year.

Erodibility of Soil Factor (ES): This factor is generally controlled by the texture of soil rather than other parameters such as structure and organic matter. ES value increases as the soil texture becomes smaller to finer, such as fine loamy soil which contains a maximum proportion of silt and smaller to finer sand due to, is highly vulnerable to erosion. ES value in Kohima district ranges in 15 classes concerning existing types of soil. Figure 3.5 b depicts the spatial variability of the soil erodibility factor of the region which varies at minimum of 0.10 to a maximum of 0.41 among the existing 12 classes of soils. The range of the ES factor varies from a minimum of 0.00 to 0.41, where close to '0' indicates less susceptibility to soil erosion and close to '0.41' is an indication of high susceptibility to soil erosion (Table 3.4 and Figure 3.5 b).

Erodibility of Rock Factor (ER): Erodibility of exposed bedrocks depends on geo-chemical properties of rock, such as dispersal of grain mass, organic matter and structure and absorbency (Wischmeier and Smith 1978). Based on the geological maps of the study area, ER values of existing rock types have been estimated from the nomogram (Wischmeier and Smith 1978) of RUSLE. The average ER value of the study area stands at 0.03 whereas it varies at a minimum 0.01 for Slates and Phyllites of Disang group to a maximum of 0.04 for sandstones Barail, Tipam and Surma groups (Table 3.4 and Figure 3.5 c).

Slope Steepness and Length Factor (LS): LS is considered a significant factor in the RUSLE model as it influences the amount of soil erosion in a specific site. LS factor has been calculated by integrating the slope factor and flow accumulation factor in SRTM DEM. This exercise carried out values of slope steepness and length (LS) factor ranges between 0 and 49 across the study area. Spatial distribution suggested that in most of the proportion of the study area, LS factor values range between 0 and 1.22 (Table 3.4 and Figure 3.5 d).

Crop Management Factor (CM): Crop management factor determines crop sequence, productivity level, depth of soil etc., thereby influencing rate of erosion and soil loss. Due to the rich diversity in the relief and slope pattern of the study area, land cover or crop pattern mapping was carried out to assess the CM factor. CM factor value varies minimum of 0.0 for dense forest areas to a maximum of 1.80 for buildup areas (Table 3.4 and Figure 3.6 a). Most parts of the study area account for a CM value below 0.25, which represents an area of dense to open forest land. It is also noted that the CM value varies in different seasons and weather conditions throughout the year.

Table 3.4**:** Test values of RUSLE factors and sub-factors for Kohima district, Nagaland

Factors	Sub-factors		Test value	Average	
Rainfall Erosivity (RE)	1620-1975		648.124-848.124	1018.984	
	1976-2260		848.124-948.124		
	2261-2488		948.124-998.124		
	2489-2703		998.124-1148.12		
	2704-2919		1148.12-1248.12		
	2920-3236		1248.12-1294.15		
Erodibility of Soil (ES)	Coarse-loamy,		0.09	0.248	
	Typic Dystrochrepts		0.11		
	Fine-loamy		0.32		
	Umbric Dystrochrepts		0.38		
	Typic Hapludults		0.31		
	Fine, Typic Paleudults		0.28		
	Umbric Dystrochrepts soil		0.38		
	Fine Loamy Lithic Udorthent		0.41		
	Coarse-loamy,		0.09		
	Typic Dystrochrepts		0.11		
Erodibility of Rock (ER)	Barail group	Shales,	0.02	0.02	0.03
		Sandstone	0.04		
	Disang group	Shales,	0.02	0.01	
		Slates,	0.01		
		Phyllites	0.01		
	Tipam group	Shales,	0.02	0.03	
		Siltstones,	0.03		
		Sandstones	0.04		
	Surma group	Sandstones	0.04	0.04	
Slope Steepness (SL)	0-10		0-10	29.80	
	10-25		10-20		
	25-35		20-30		
	35-45		30-40		
	45-80		40-49		
Cover Management (CM)	Dense Forest		0.01	0.25	
	Open Forest		0.05		
	Water bodies		0.00		
	Shrubs land		0.05		

	Build up area	1.00	
	Waste Land	0.08	
	Agricultural land	0.60	
Conservation Practices (CP)	Dense Forest	1.00	0.52
	Open Forest	0.70	
	Water bodies	0.00	
	Shrubs land	0.70	
	Build up area	0.10	
	Waste Land	0.70	
	Agricultural land	0.50	

Conservation Practices Factor (CP): Erosion-controlling biological and mechanical measures are considered a conservation practice in the RUSLE model. The frequency of these erosion mitigating measures influences the CP value and rate of soil erosion. To that, the CP values were assigned considering the land use pattern of the study region. Buildup area accounts for low CP value whereas, dense forest area accounts for higher CP value. The CP value varies from 0.1–1.0 across the study region to land use/cover pattern (Table 3.4 and Figure 3.6 b).

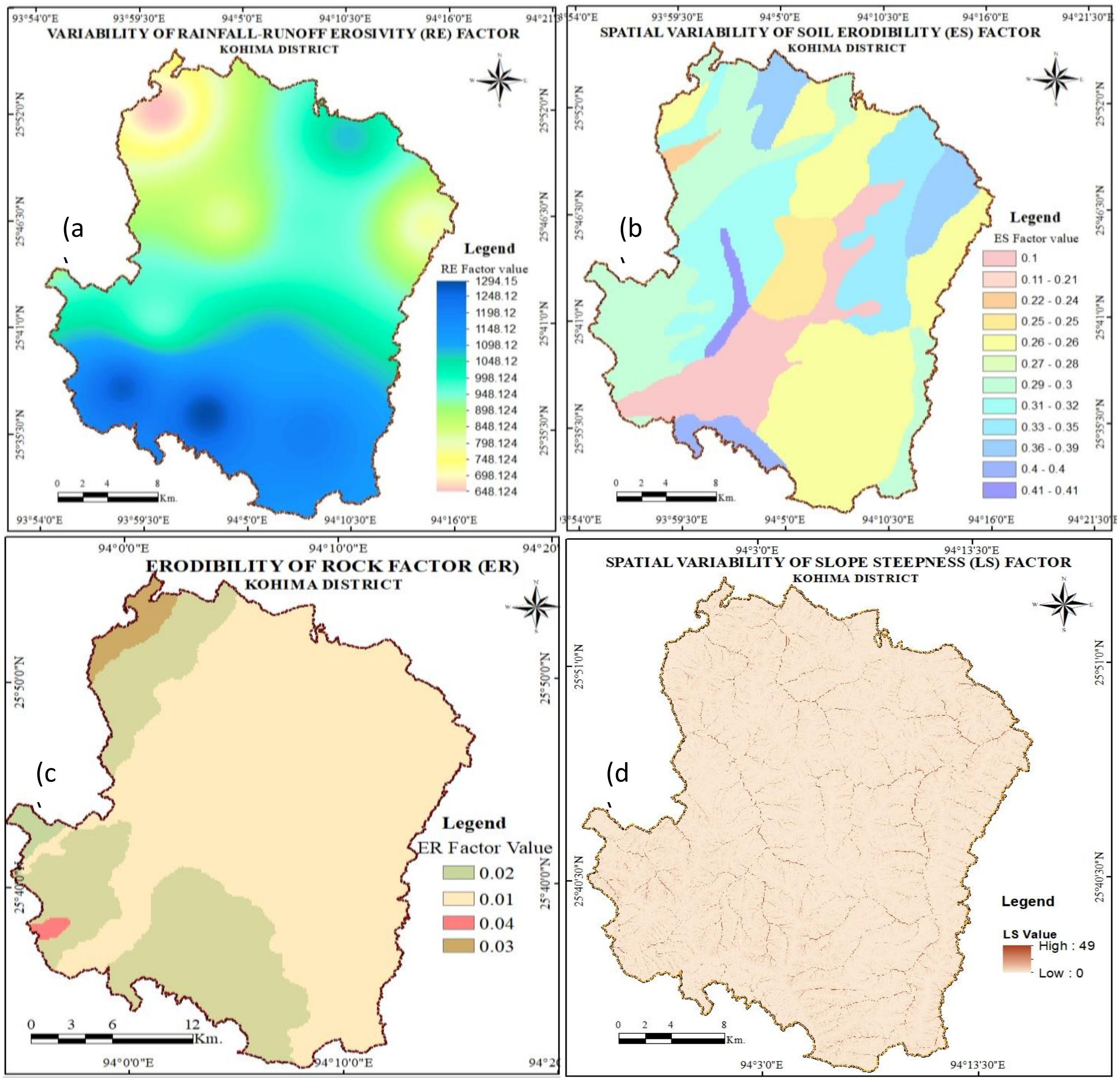


Figure 3.5: Spatial variability of a) rainfall erosivity (RE), b) soil erodibility (ES), c) rock erodibility (ER) and d) slope length and steepness (LS).

Spatial Variability of Erosion and Soil Loss (A)

Spatial variability of erosion and soil loss (A) has been computed by superimposing and multiplying the prepared raster map layers of all six RUSLE factors (A= RE x ES x ER x LS x CM x CP) through Map Algebra raster calculator spatial analysis tool of ArcMap GIS software. The outcome map of overlay operation shows that the spatial variability of annual erosion and soil loss rate ranges from 0–92.18 t/ha/year across the region. This range has been classified into four erosion intensity zones: these are low (below 20 t/ha/year), moderate (20-40 t/ha/year), high (40-60 t/ha/year), and very high (above 60 t/ha/year) erosion intensity zones.

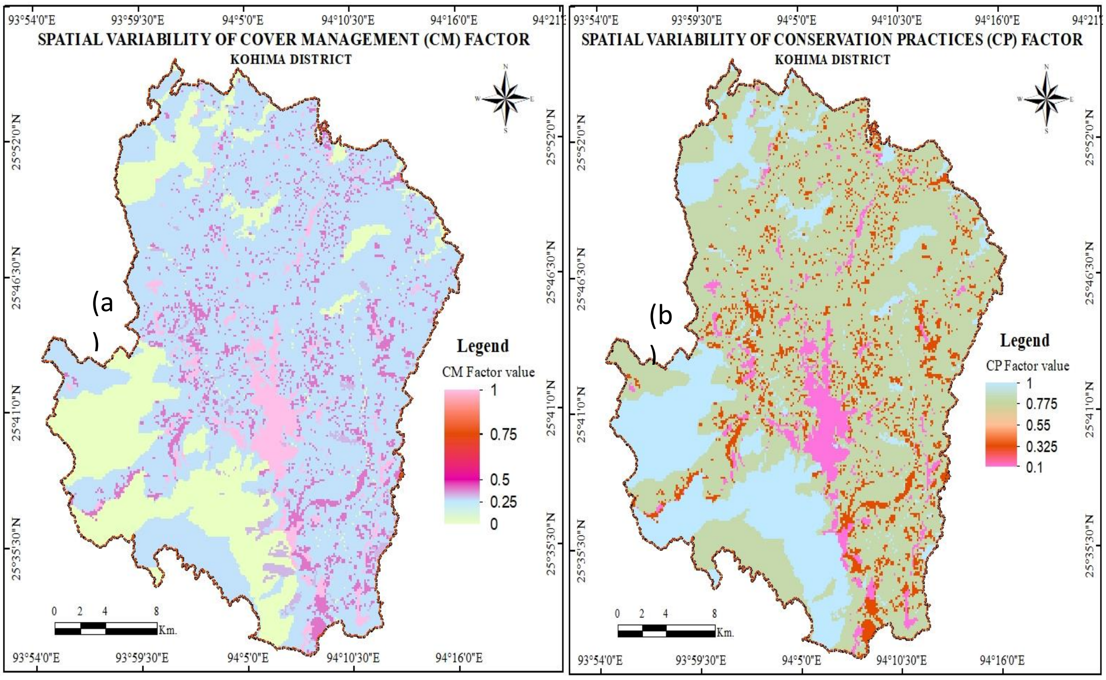


Figure 3.6: Spatial variability of a) Cover Management factor (CM) and b) Conservation Practices factor (CP).

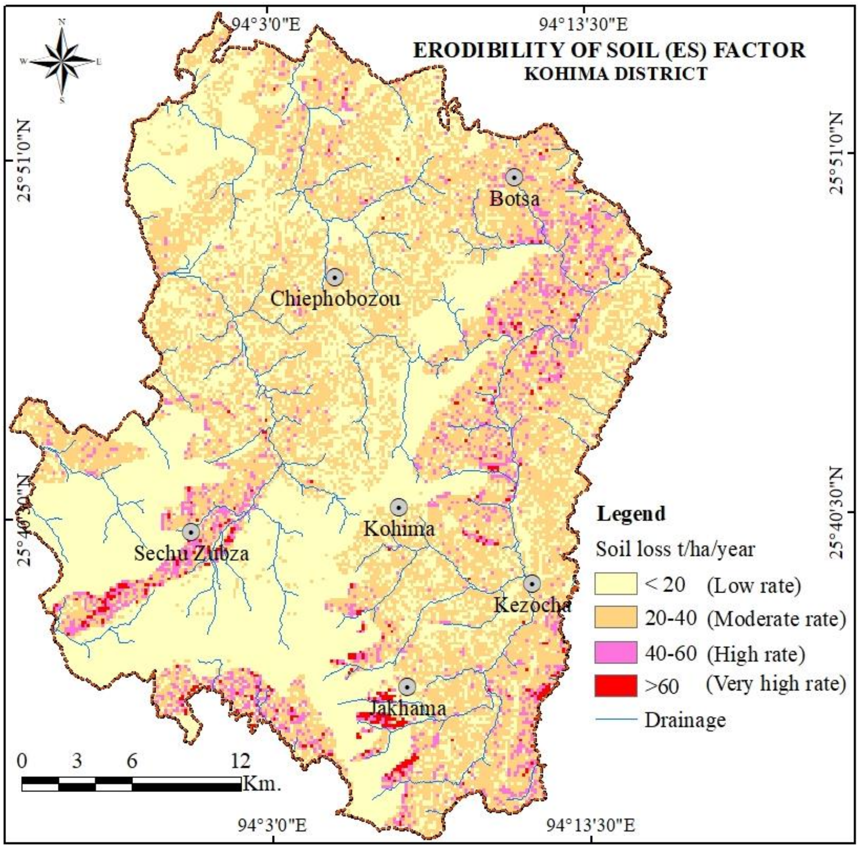


Figure 3.7: Spatial variability Erosion and Soil loss (A).

3.2.2. Erosion Induced Geomorphic Hazards susceptibility

The Northeastern region of India faces a significant geo-environmental issue due to the substantial erosion rate and related geomorphic hazards that occur during heavy rainfall. This problem is exacerbated by the region's high annual average rainfall, which ranges from 2500-3200mm (Sengupta, 2010, Dikshit et al. 2019, Gariano et al. 2019, Teja 2019, Harilal et al 2019). There are various geospatial technologies that have been developed based on recent research on erosion and rain-induced geomorphic hazards (such as mass movement, debris fall, and landslides) in the Himalayas. However, most of these technologies have focused on the central Himalaya region (Dash et al., 2000; Naithani et al., 2002; Sarkar and Gupta, 2005; Shantanu et al., 2013; Martha et al., 2015) and the western Himalaya region (Mukhopadhyay et al., 2005; Roy et al., 2018; Kumar et al., 2018; Pradhan et al., 2019; Banerjee and Dimri, 2019; Kumar et al., 2019). On the other hand, there is a lack of studies available for the Northeastern region (Umrao et al., 2017; Sarkar et al., 2017; Dikshit and Satyam, 2018; Bera et al., 2019). Specifically, there is no information available for the Nagaland state. It is crucial to consider the risk of rain and erosion-induced geomorphic hazards in the research area in order to accurately depict the Nagaland state and the Northeastern region. Nevertheless, the examination of different forms of erosion and geomorphic hazards caused by rainfall, such as mass movements, landslides, slope failures, and others, necessitates the use of distinct approaches and procedures for each. The current study provides a comprehensive analysis of geomorphic risks caused by increased erosion during the rainy season in the Kohima district of Nagaland. During the field validation of the erosion intensity zone map, numerous locations have been identified in the study areas where a significant erosion rate has been causing various geomorphic hazards, including mass movement, rock fall, debris fall, landslide, and slope failure. These hazards have subsequently impacted infrastructure, agricultural land, settlements, rural livelihood, natural resources, and the wildlife ecosystem. An integrated map of erosion-induced geomorphic hazard susceptibility zones was created for the research region, taking into account the various locations and spatial variability of erosion rate and geophysical properties. The map identifies four zones: low, moderate, high, and extremely high.

Area of low susceptibility to erosion-induced geomorphic hazards: The areas having soil erosion rate below 20 t/ha/year and least stressed geophysical characteristics (comprised of fluvial plain and valleys over geology of shales, siltstones, sandstones rock) have been considered as low susceptibility zone of erosion induced geomorphic hazard (Figure 3.8). No significant mass movement events are seen in such areas.

Area of moderate susceptibility to erosion-induced geomorphic hazards: The areas having soil erosion rate 20-40 t/ha/year and moderately stressed geophysical background (comprised of river terraces and gentle down-slope susceptibility zone of erosion induced geomorphic hazards (Figure 3.8). Landslides and slope failure due to the erosion of slopes along rivers are common types of geomorphic hazards in this zone.

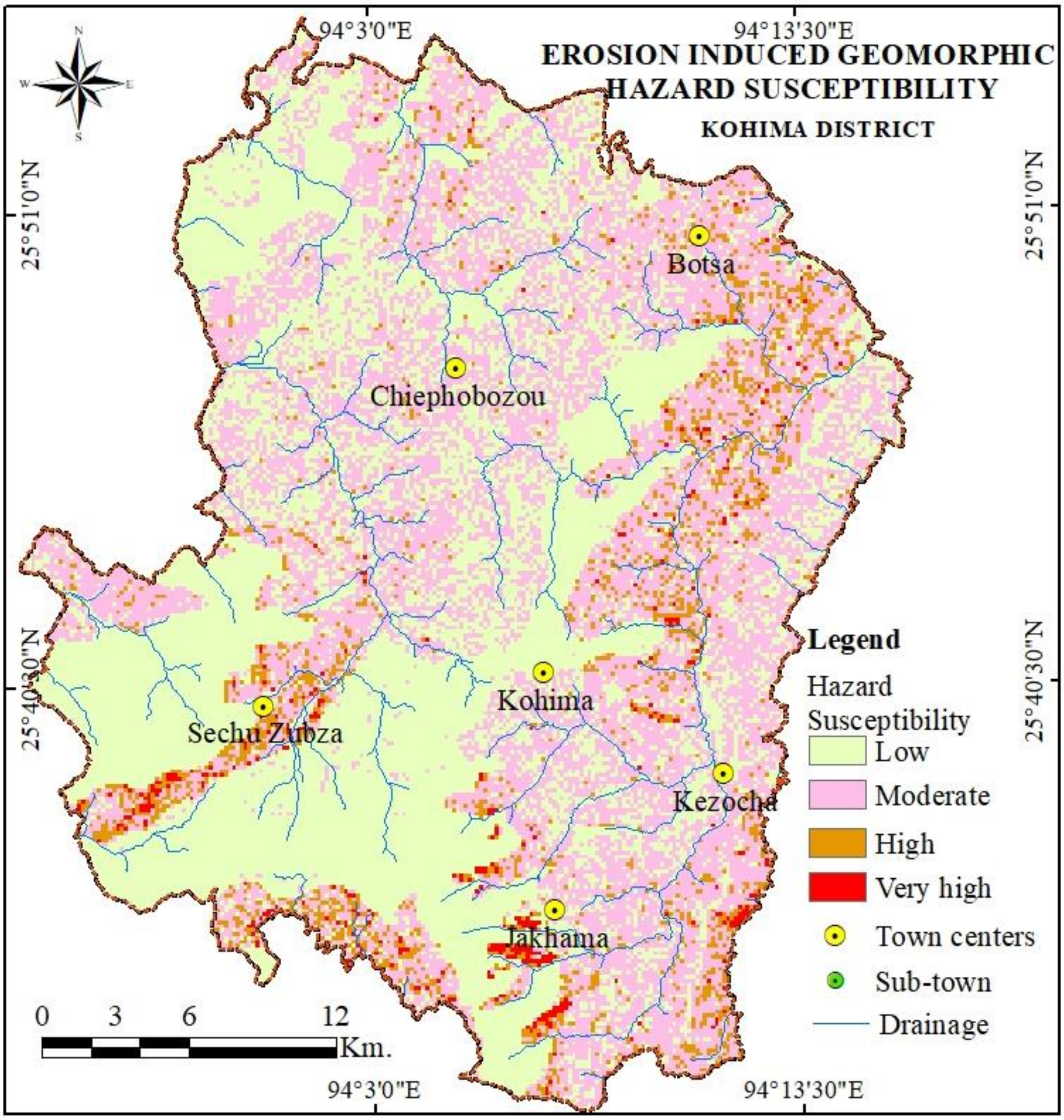


Figure 3.8: Erosion induced geomorphic hazards susceptibility map of Kohima district, Nagaland.

Area of high susceptibility to erosion-induced geomorphic hazards: The areas having soil erosion rate 40-60 t/ha/year and moderate to highly stressed geophysical characteristics (comprised of steep up-slope hilly geomorphology over a geological background of shales, slates and phyllites) have been identified to high susceptibility zone of erosion induced geomorphic hazard (Figure 3.8). Land subsidence with large spatial extension is found in this zone. Anthropogenically accelerated erosion and subsequent landslide, rock fall, and debris flow along roads, and urban settlements of Kohima city are also found in this zone.

Area of very high susceptibility to erosion-induced geomorphic hazards: The areas having soil erosion rate above 60 t/ha/year and highly to extremely stressed geophysical characteristics (comprises of steep up-slope hills, strike ridge areas, high relief structural hills geomorphology over a geological background of Shales, sandstone.) have been identified as very high-risk zone of erosion induced geomorphic hazard (Figure 3.8). Active landslides and slope failure geomorphic hazards are commonly seen in this zone.

3.3. Landslide Vulnerability of Kohima District

Geo-environmentally, the Northeast region of India region is highly susceptible to landslide geomorphic hazard due to frequent seismotectonic activity, humid tropical to humid sub-temperate climate (receives 1600-3200mm mean rainfall), young and highly erodible rock formations (mainly comprised of sandstones, siltstones and shales), fragmented reshaping geomorphology, high erodibility of surface and sub-surface soils. In addition, human activities have been hastening the occurrence of landslides by means of fast, uncontrolled urban expansion, the development of infrastructure, and the practice of shifting cultivation on unstable slopes. These activities have resulted in economic and human losses, as well as environmental degradation, due to extensive deforestation and desertification (Rawat 2013, Rawat and Furkumzuk, 2013). Landslides are a significant geomorphic hazard in the Northern region of India. They occur frequently throughout the year and have detrimental effects on both the natural environment and the local economy. These effects include the removal of forests and vegetation cover, degradation of agricultural land, destruction of crops, loss of human and livestock lives, harm to wildlife, and damage to infrastructure such as roads, canals, bridges, communication networks, and electricity networks. The Northern India has a significant record of landslide catastrophes, which have been studied by several scholars at different intervals. The study conducted by Chopra et al. (1977) examined the instability and mass migration occurring along the highways connecting Sikkim and North Bengal. Haigh et al. conducted case studies on road-induced landslides, hydrological landslides, and neotectonic landslides in several regions of the central Himalaya in 1992, 1993, 1995, and 1997. Anbarasu et al. (2010) evaluated the instability of the Lanta Khola landslide in the Sikkim Himalayan area. Balamurugan et al. (2016) conducted a study on the mapping of landslide susceptibility zones in a specific area of NH-39, Manipur, India. They utilized the frequency ratio and fuzzy gamma operator models for this purpose. Ghosh (2013) conducted research on landslides triggered by earthquakes. Anbalagan et al. (2015) conducted a study on the mapping of landslide hazard zones in Lachung Valley, Sikkim. Barman and Rao (2019) conducted a study on the mapping of landslide hazard susceptibility in the upper Tuirial watershed, Mizoram using Remote Sensing and GIS methods. Research conducted by Agrawal et al. in 2023 focused on seismic landslides in the Meghalaya state of the eastern Himalaya area. In the context of Nagaland state in northeast India, landslides occur with high frequency, similar to other areas in the eastern Himalayas. These landslides have significant environmental and social consequences. However, to date, no comprehensive study has been conducted that examines both seismic and rainfall-induced landslides on a regional scale. Several researchers, including Aier et al. (2012), have conducted site-based case studies. For example, Aier et al. (2012) examined the instability of the Merhulietsa landslide in the Kohima district. Rawat (2014 and 2017) conducted a watershed-based study on landslide hazard and its repercussions. Nokendangba et al. (2021) conducted a study on a landslide issue that occurred along NH 29 in the Kevüza Area. Therefore, it has been crucial to examine regions impacted by landslides in order to apply necessary measures to reduce their impact.

3.3.1. Methodology

3.3.1.1. Geo-environmental GIS database development

Geo-environmental GIS offers essential spatial and attribute information on the geophysical, topographic, hydro-meteorological, and biological elements that influence landslides (Rawat et al., 2011, 2012, 2014, 2017, and 2023). The study of geophysical elements, including seismotectonics, geology, geomorphic landforms, soil types, and drainage, was conducted using Survey of India (SOI) topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000 and Google Earth pictures at various sizes. The topographic parameters, including relief pattern, slope gradient, slope aspect, flow accumulation, and drainage morphometry, were studied using Digital Elevation Modelling (DEM) based on NASA-STRM satellite images with a spatial resolution of 30 units. The study analysed ecological parameters, including plant kinds, land use patterns, and soil erosivity, using USGS-Landsat satellite images with a spatial resolution of 30 meters. The study focused on hydrometeorological parameters, including rainfall, runoff data, and erosion rate. Secondary data from various sources were collected and analysed. Rainfall data spanning three decades (1991–2022) was obtained from the NASA Power Data Access Viewer (NASA-DAV: https://power.larc.nasa.gov/data-access-viewer/) as well as from four ground-based meteorological observatories operated by the Indian Meteorological Department (IMD).

The rainfall data collected from various areas was utilized to determine the average monthly and yearly rainfall. This data was then transformed into a raster layer using the inverse distance weighting (IDW) method of interpolation to analyse the geographical distribution of rainfall. The current research incorporates runoff and soil erosion rate data obtained from previous investigations (Rawat et al., 2023).

3.3.1.2. Integration of landslide triggering factors for hazard zonation through Analytic Hierarchy Process in GIS environment

The Analytical Hierarchy Process (AHP), developed by Saaty (1980), is a highly dependable, accurate, and extensively utilized technique for extracting and quantifying subjective judgments in multi-criteria decision-making (MCDM). The integration of this process with Digital Elevation Modelling (DEM) in a GIS environment has further enhanced its credibility (Anand et al., 2022). Hence, this study has examined the weight values assigned to each causative element (thematic layers) and sub-factors (classes of thematic layers) of the landslide using this technique. The weight value attributed to different sub-factors or classes of thematic layers ranges from 0 to 9. A higher weight value suggests a greater effect on landslide incidence (Table 3.5). In order to create the final landslide hazard zonation map, all vector layers of thematic GIS maps that represent the causative variables are translated into a raster format. This allows for a spatial overlay operation to be performed using a Digital Elevation Model (DEM). Prior to the overlay operation, the weight value of each factor and sub-factor is determined using the Analytic Hierarchy Process (AHP) matrix. The AHP matrix is a grid with an equal number of columns and rows, where scores are recorded on one side of the diagonal. The diagonal of the matrix contains values of 1 (Saaty, 1990). In order to create a pair-wise judgment matrix, each criterion has been evaluated against every other criterion by giving a relative scale ranging from 1 to 9. This scale is determined based on several criteria and preferences, as outlined in Table 3.5. Afterwards, the weighted values of each criterion have been determined using the AHP pairwise comparison matrix (Table 3.6). Each row of the pairwise comparison matrix values represent the relative significance of the two criteria (Table 3.6).

Table 3.5: Description of scales for pair comparison with AHP (Saaty, 1990)

Scales	Degree of preferences	Descriptions
1	Equally important	The contribution of the two factors is equally important
2	Intermediate value	In between two judgments
3	Slightly important	Experiences and judgment slightly tend to certain factor
4	Intermediate value	In between two judgments
5	Quite important	Experiences and judgment strongly tend to certain factor
6	Intermediate value	In between two judgments
7	Extremely important	Experiences and judgment extremely strongly tend to certain factor
8	Intermediate value	In between two judgments
9	Absolutely important	There is sufficient evidence for absolutely tending to certain factor

To examine whether the pairwise comparisons are consistent or not, the consistency ratio (CR) was calculated by applying the formula introduced by Kolat et al., 2012. Consistency ratio (CR) is an indicator of the degree of consistency or inconsistency (Chen et al. 2010; Feizizadeh and Blaschke, 2013). If the CR < 0.10, it indicates a good level of consistency in recognizing the class weights.

$$\text{Consistency Ratio (C.R.)} = \frac{\text{Consistency index (CI)}}{\text{Random Consistency Index (RI)}}$$

$$\text{Consistency index (CI)} = ßmax - n \,/\, n - 1$$

Where, λmax represents the major eigenvalue and n is the number of factors.

RI is a Random consistency index, taken from a sample of randomly generated matrices, as suggested by Saaty, 1980.

The calculated consistency ratio (CR) in the present study stands at 0.046, which points out that the comparisons of characteristics are very consistent and the weights (Table 3.6) are suitable for spatial variability assessment of landslide hazard.

Table 3.6: AHP pairwise comparison matrix, weights, random index value and consistency ratio of spatial data (Saaty, 1990).

S.N.	Landslide Causative Factors	Pairwise comparison matrix in between causative factors												Weights
		SL	RF	SH	LSD	LMD	DD	GL	GM	EL	SA	LU	ST	
1	Slope (SL)	1	2	3	4	5	6	7	8	9	9	10	10	**0.296**
2	Rainfall (RF)	1/2	1	2	3	4	5	6	7	8	9	10	10	**0.218**
3	Seismic hazard (SH)	1/3	1/2	1	2	3	4	5	6	7	8	9	9	**0.158**
4	Landslide density (LSD)	1/4	1/3	½	1	2	3	4	5	6	7	8	9	**0.112**
5	Lineament density (LMD)	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	**0.082**
6	Drainage density (DD)	1/6	1/5	¼	1/3	1/2	1	2	3	4	5	6	7	**0.059**
7	Geology (GL)	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	**0.052**
8	Geomorphology (GM)	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	**0.038**
9	Elevation (EL)	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	**0.027**
10	Slope aspect (SA)	1/9	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	**0.021**
11	Landuse pattern (LU)	1/9	1/9	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	**0.019**
12	Soil types (ST)	1/9	1/9	1/9	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	**0.016**
Consistency ratio (CR)														**0.046**

Slope gradient: Slope gradient is one of the most important causative factors of landslide hazard. As the steepness of the slope increases, accumulated pressure in surface and subsurface material (soil, rocks, unconsolidated debris etc.) usually increases as well. The slope gradient ranges below 15° in the alluvial plain area in the northern part to 81° in the mountain area southern part respectively which is classified into five categories: gentle (<15°), moderate (15°–30°), high (30°–45°), steep (45°-60°) and very steep (>60°). The spatial variability of slope gradient in Kohima district shows that a significant proportion about 52% of the total area dominated by high to steep slopes ranging from 30° to 80° (Figure 2.3). Very steep slopes (> 60°) are less frequent in the area, which is about 6.2% of the total area. The weight value of slope gradient calculated through the Analytical Hierarchy Process

(AHP) stands at 0.294 whereas the scale for pairwise matrix stands at 1, 3, 5, 7, and 9 for gentle, moderate, high, steep and very steep slopes respectively (Table 3.8).

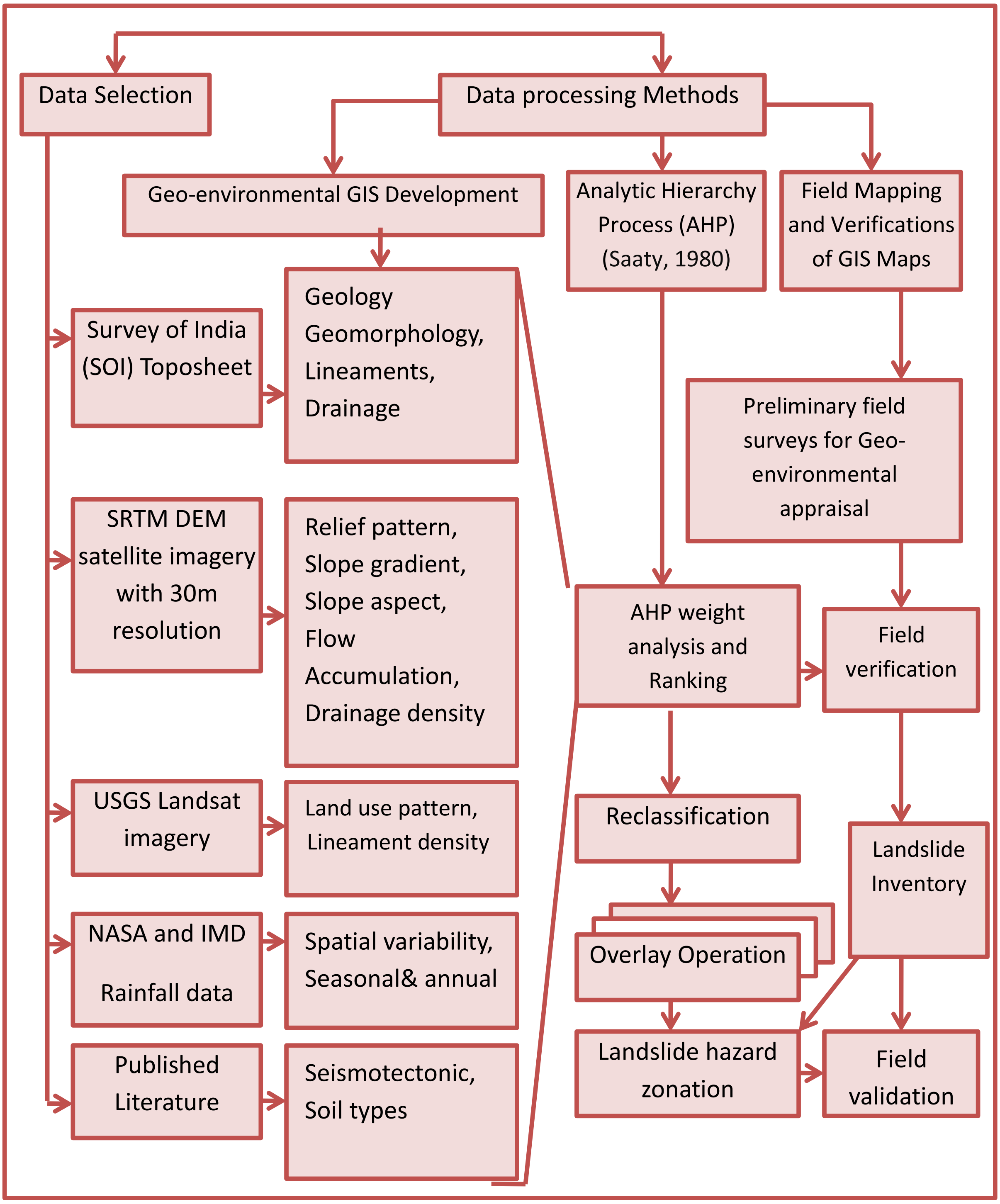


Figure 3.9: Methodology for landslide hazard zonation in Kohima district. Nagaland

Rainfall pattern: The research region has a range of elevations, from 204m to 2953m, and exhibits several microclimatic conditions based on these elevations. Specifically, there are four microclimatic conditions present: humid tropical (below 900m), humid subtropical (900m-1750m), humid temperate (1750m-2600m), and humid sub-temperate (2600m-

3450m). The rainfall data obtained from 12 meteorological stations during the past three decades (1991-2022) encompasses all four microclimatic zones. The average annual rainfall data from these 12 sites was transformed into GIS map format, including both vector and raster formats, in order to calculate the geographical distribution of average annual rainfall. This information can be found in Table 3.8 and Figure 3.10. The rainfall variability map shows that the average annual rainfall varies from a minimum of 1620mm in the lowest relief areas (<300m) with a humid tropical climate, to a maximum of 3236mm in the highest relief areas (>2000m) with a humid sub-temperate climate. The average rainfall for the region is 2435.17mm. Heavy and continuous rainfall throughout the rainy season is a well acknowledged source of precipitation seepage. This, in turn, saturates and weakens slope materials, resulting in various kinds of landslides such as gully erosion, mudslides, soil movement, rock fall, and debris falls in mountainous areas. The geographical distribution of yearly and monsoon rainfall indicates that almost 50% of the whole region experiences high to extreme-intensity rainfall, making it highly susceptible to landslide hazards. The weight value of rainfall in the Analytical Hierarchy Process (AHP) is 0.215. The scale for the pairwise matrix is as follows: 4 for annual average rainfall < 1975mm, 5 for rainfall between 1976-2260 mm, 6 for rainfall between 2261-2488mm, 7 for rainfall between 2489-2703mm, 8 for rainfall between 2709-2919mm, and 9 for rainfall between 2920-3236mm (Table 3.8).

Seismicity: The areas located along converging tectonic plate borders are classified as high seismic hazard zones. The Himalaya region experiences microearthquakes throughout the year, in addition to high magnitude earthquakes during a specific period. This is because the region is composed of emerged 'Thethys' geosynclines, which were formed between two converging plates: the Indian plate (consisting of the Indus Sea, Australia, etc.) from the south, and the Eurasian plate (including Asian and Russian land, etc.) from the north (Nakata, 1972; Valdiya, 1976; Thakur, 2004). The Kohima region has frequent earthquake activity. A seismic hazard zonation map of the research region has been created by including current seismic investigations, (Pal et al. 2008, Gupta et al. 2022, Kayal 2022, Agarwal 2023), historical earthquake data, local tectonics, geology, and geomorphology. Hence, seismic data over the past four decades of the research area was gathered from the National Centre for Seismology (NCS). According to the earthquake statistics, there have been a total of 1102 earthquakes in Kohima district from 1982 to 2022, as indicated in Table 3.1. The statistical analysis of the seismic data indicates that around 27 earthquake occurrences occur in the region on a yearly basis. Out of these events, 76% are classified as microearthquakes with a magnitude less than 4, while the other 24% are categorized as moderate to high earthquakes with a magnitude of 4 or above. This information is presented in Table 3.1 and Figure 3.1. The spatial distribution map of these earthquake occurrences is overlaid onto the structural lineament map and geology map to create a micro-seismic danger zone map of the region (Figure 3.3). This map illustrates that the majority of seismic events occur along tectonic lineaments, such as faults, thrusts, lithological shear zones, and transition zones. These geological features contribute to the instability of the geology and geomorphology. The seismicity weight value for the study region, as determined by the Analytical Hierarchy Process (AHP), is 0.158. The pairwise matrix scale for the seismic hazard zones is 5 for moderate, 7 for high, and 9 for extremely high (Table 3.8).

Table 3.7: Average annual rainfall at different elevations in and around Kohima district, Nagaland (1991-2022).

Station Name	**Elevation (in m)**	**Data monitored by**	**Authority of data**	**Average annual rainfall (in mm)**
1. Dimapur	175	observatory	IMD	1560.75
2. Lukuto	256	Satellite	NASA	1620.28
3.Tukuliqu	570	Satellite	NASA	1935.85
4. Chiephobozou	800	Satellite	NASA	2055.50
5. Mokokchung	1085	observatory	IMD	2355.50
6. Sechu Zubza	1100	observatory	Nagaland govt.	2380.75
7. Nerhema	1230	Satellite	NASA	2415.28
8. Botsa	1470	Satellite	NASA	2690.48
9. Kohima Sadar	1610	observatory	Nagaland govt.	2780.60
10. Viswema	1870	Satellite	NASA	3015.80
11. Khonoma	2675	Satellite	NASA	3175.75
12. Japfii peak	3040	Satellite	NASA	3235.60
Average	**1323**	**-**	**-**	**2435.17**

Lineament density: Tectonic lineaments, such as faults, thrusts, strike ridges, and river valleys, are geological structures that indicate neotectonic or microseismic activity in an area. These structures can be identified through field-based geomorphological mapping, which includes the analysis of multilevel terraces, triangular facets, and landslides. Geohydrological mapping, which involves studying the presence of water springs, waterfalls, and groundwater aquifers, can also help identify these activities. The occurrence of landslides along these geological features is commonly reported in the Himalayas as a whole and specifically in the research region (Pachauri and Pant 1992; Mathew et al. 2007; Ramli et al. 2010). Consequently, a map displaying the density of lineaments in the research region has been created, depicting five distinct classes of lineament density (Figure 2.10). The weight value of lineament density for the study region, as determined by the Analytical Hierarchy Process (AHP), is 0.109. The scale used for the pairwise matrix is as follows: 1 for lineament density less than 0.40 km/km^2, 3 for lineament density between 0.41 and 0.80 km/km^2, 5 for lineament density between 0.81 and 1.20 km/km^2, 7 for lineament density between 1.21 and 1.60 km/km2, and 9 for lineament density between 1.61 and 2.00 km/km2 (Table 3.8).

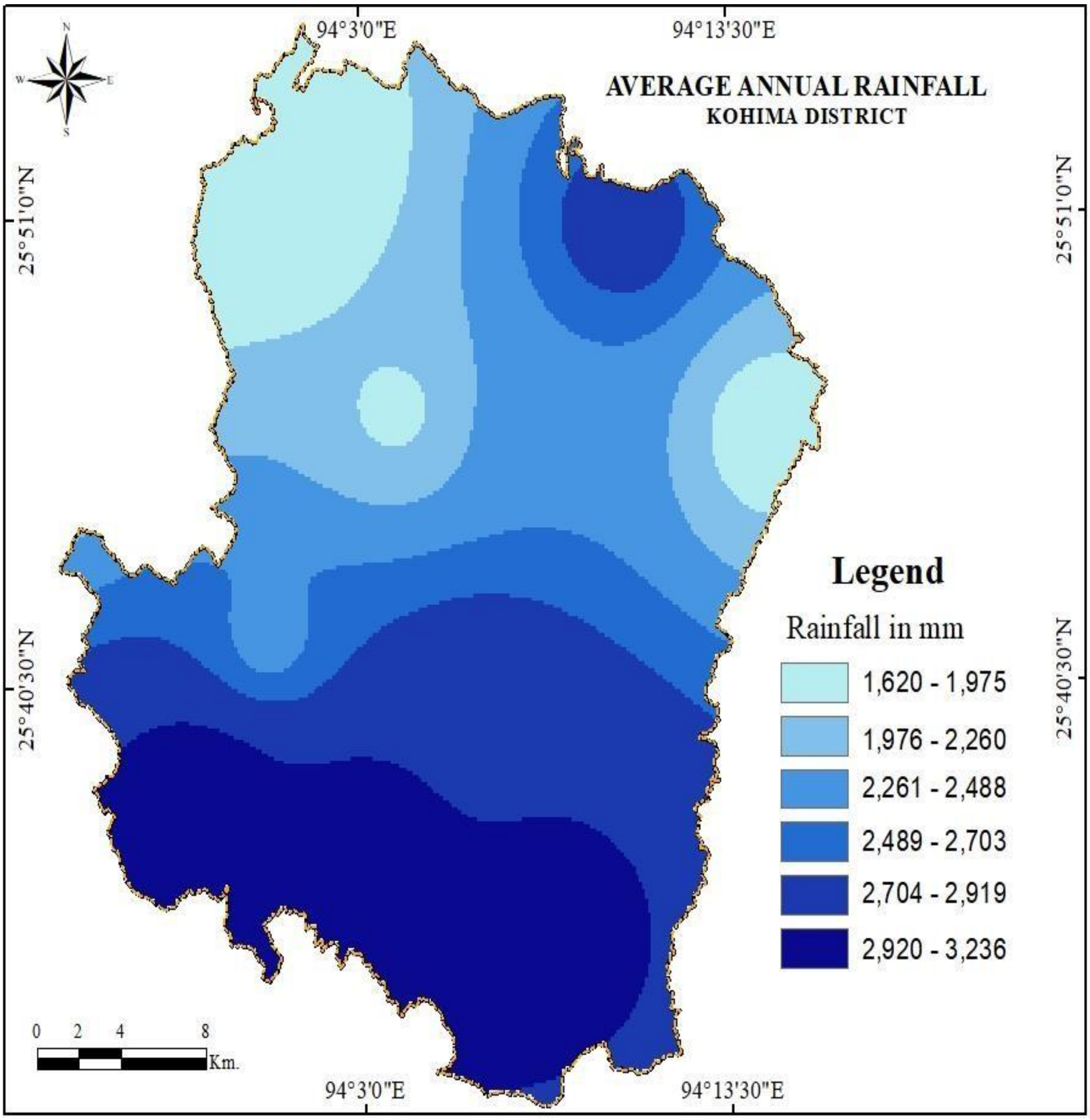


Figure 3.10: Average annual rainfall of Kohima district (1991-2022)

Table 3.8: Weights and rating matrix used for reclassification and overlay of GIS layers of landslide triggering factors and their sub-factors.

Sl. No.	**Factor**	**Classes**	**Rating**	**Weights**
1	Slope (in degree)	0-10	1	0.294
		10-25	3	
		25-35	5	
		35-45	7	
		45-80	9	
2	Rainfall (in mm)	1620-1975	4	0.215
		1976-2260	5	
		2261-2488	6	
		2489-2703	7	
		2704-2919	8	
		>3236	9	
3	Earthquake hazard index	Moderate hazard zone	5	0.154
		High hazard zone	7	
		Very high hazard zone	9	
4	Lineament density (km/km2)	0- 0.40	1	0.109
		0.41-0.80	3	
		0.81-1.20	5	
		1.21-1.60	7	
		1.61-2.00	9	
5	Drainage density (km/km2)	<2	1	0.076
		2-4	2	
		4-6	6	
		>6	8	
6	Geology	Tipam group	4	0.054
		Surma group	6	
		Disang group	8	
		Barail group	9	
7	Geomorphology	Alluvial plain	1	0.038
		Terraced land	3	
		Mid slope valleys	4	
		Piedmont zone	5	
		Low dissected hills	6	

		Moderately dissected hills	7	
		Highly dissected hills	8	
		Mass wasting sites/ active landslides	9	
8	Landslide density (in 10 km2)	0-1	2	0.112
		1-2	3	
		2-7	5	
		7-9	7	
		9-12	9	
9	Elevation (in m)	204-824	3	0.038
		825-1160	6	
		1161-1600	7	
		1601-2160	8	
		2161-2953	9	
10	Slope Aspects	Flat	0	0.021
		North	8	
		North-east	9	
		East	9	
		South-east	7	
		South-east	8	
		South-west	9	
		West	5	
		North-west	6	
11	Landuse pattern	Dense forest land	3	0.019
		Open forest land	4	
		Agricultural land	5	
		Built-up area	7	
		Waste land/Barren land	9	
12	Soils	Fine-loamy Typic Dystrudepts	4	0.016
		Fine-loamy Typic Argiudolls	5	
		Fine-skeletal Cumulic Hapludolls	5	
		Coarse-loamy Pachic Dystrudepts	6	
		Fine-loamy Typic	6	

		Paleudolls		
		Coarse- loamy Typic Hapludolls	6	
		Loamy-skeletal Typic Udorthents	7	
		Loamy-skeletal Entic Hapludolls	7	
		Loamy-skeletal Lithic Udorthents	9	

Drainage density: It is one of the significant drivers of geomorphic hazards such as erosion, mudflow, landslide, slope failure etc. Kohima district comprises 1 sixth-order river, 8 fifth-order rivers and thousands of fourth-order to first-order rivers. The spatial variability of drainage density of the study area ranges from 1.5km/km2 to 9km/km2 which has been categorized into four different classes and assigned weight values to their significance to landslide hazard (Figure 3.11). The Analytical Hierarchy Process (AHP) weight value of drainage density for the study area stands at 0.076, whereas the scale for pairwise matrix stands 1, 2, 6, and 8 for drainage density below 2, 2-4, 4-6 and above 6 km/km2 (Table 3.8).

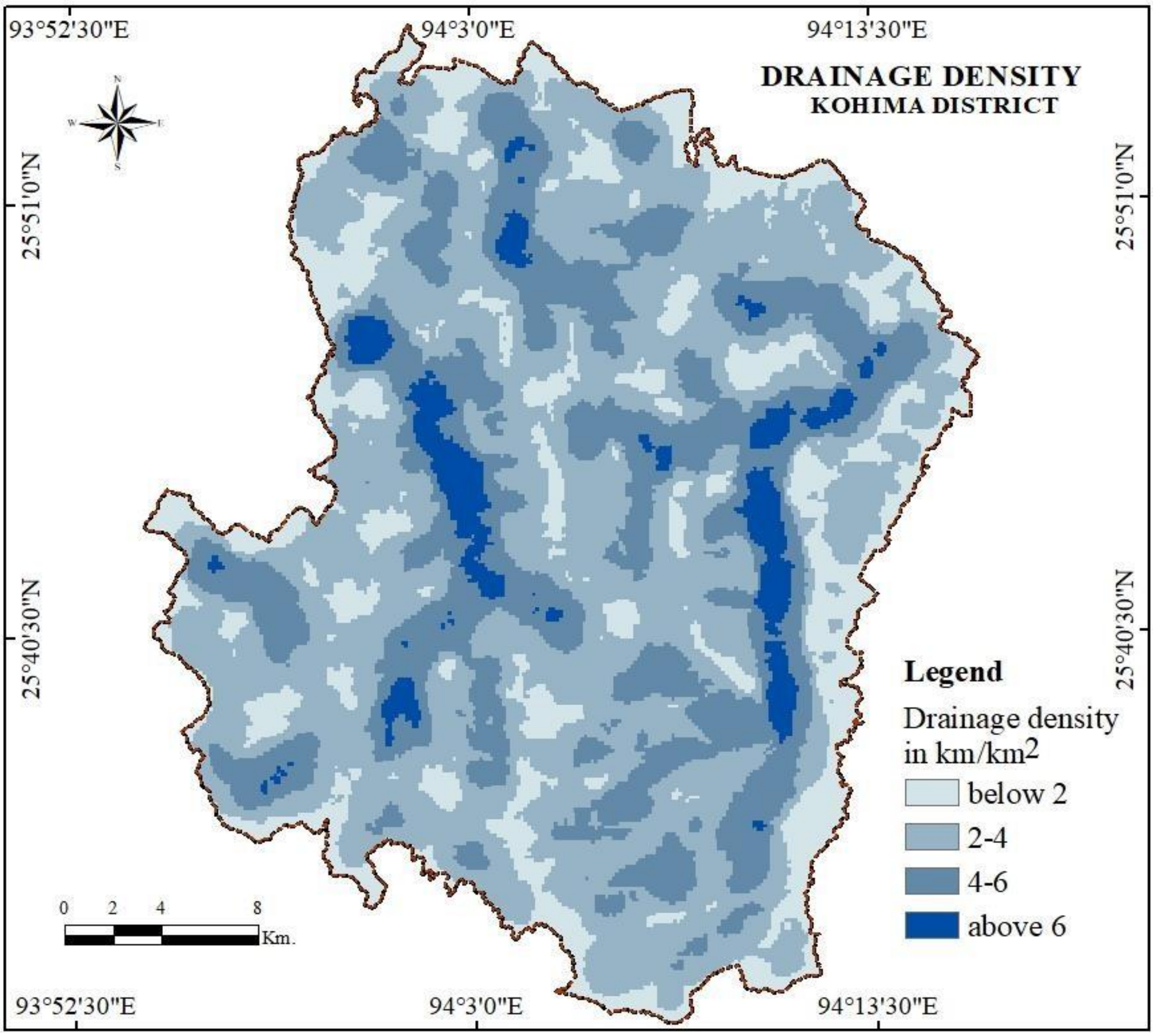


Figure 3.11: Drainage density of Kohima district, Nagaland

Geology: The Kohima region is geologically susceptible to landslide threats due to the youthful, fractured, and decomposed character of its rocks, as mentioned in the introductory section. The region consists of four main lithological portions, namely the Barail group, Disang group, Surma group, and Tipam group, arranged from south to north (Figure 2.9). The Barail group is composed of rocks such as grained sandstone, silty shale, and carbonaceous shale, together with small coal seams (Srivastava and Pandey 2011). The Disang group consists of carbonaceous, ferruginous, concretionary shales that range in color from dark to black. It also contains a small number of interbeds of siltstones and sandstones (Srivastava et al. 2013). The Surma Group is composed of a sequence of alternating layers of shales, siltstones, sandy shales, and sandstones, occasionally containing conglomerate beds (Holtrop and Keizer, 1970). The Tipam group comprises the Lakwa Sandstone, as documented by Bhandari et al. (1975) and Rawat (2004). The presence of multilevel river terraces, a high concentration of landslides (including rock fall, debris fall, creeping, and subsidence), slope failure, and fractured lithology along faults, thrusts, and significant fractures provide clear geological evidence that the region is unstable. The geology weight value for the research region according to the Analytical Hierarchy Process (AHP) is 0.054. The pairwise matrix scale for lithology of the Tipam group, Suma group, Disang group, and Barail group is 4, 6, 8, and 9 accordingly (Table 3.8).

Geomorphology: Geomorphology is a significant factor in the development of landslides and other geomorphic hazards, including erosion, mass movement, debris flow, and slope failure (Ramasamy et al., 2021). Geomorphological research was conducted using GIS technology and verified by thorough field mapping. The study indicates that the Kohima district exhibits several secondary landforms at the local level, including tectonic, fluvial, and pluvial features. Based on the characteristics of geostructural lineaments, geological composition, topography, slope, and drainage system, the study area can be classified into different types: a river bed formed by the action of a river, an alluvial fan, an alluvial piedmont, hills with multiple levels of erosion (low, moderate, high), and hills with multiple levels of structural formation (low, moderate, high). Figure 2.7 in chapter 2 illustrates the geographical arrangement of several landforms in the Kohima area. The observable alteration in the geomorphology provides clear evidence of the region's instability, since new and younger landforms such as fluvial fans, piedmont zones, and tectonic scars are forming and modifying the area. The weight value of geomorphology for the study region, as determined by the Analytical Hierarchy Process (AHP), is 0.038. The pairwise matrix scale for different types of landforms spans from 1 to 9, as shown in Table 3.8.

Landslide inventory: A comprehensive field study is planned to determine the geographical distribution of landslides and create a landslide inventory map. This would involve employing created thematic maps, such as those depicting geology, geomorphology, lineament, relief, and slope, as well as SOI toposheets. A total of 434 landslides, including rock fall, debris fall, slumps, and land creeping, were identified and their relationship with causal elements was established (Figure 3.12). The spatial distribution of landslide frequency varies based on factors such as elevation, slope gradient, geomorphology, and structural lineaments. Regions characterized by significant variations in elevation, slope gradient, and lineament density experience a heightened occurrence of landslides, particularly in locations with highly dissected hilltops, moist hill slopes composed of previous landslide debris, and elevated hanging river basins. Figure 3.13(a) illustrates the significant occurrence of landslides in high-elevation regions with slope gradients above 26º. The frequency of landslides increases proportionally with higher elevation and steeper slope gradients. Figure 3.13 (b) illustrates the distribution of landslides, showing various types of landforms and structural features such as thrusts, faults, lithological fractures, and joint sets. The AHP weight values are assigned based on the landslide density factor. The assigned values are 2, 3, 5, 7, and 9 for landslide densities of less than 1, 1-2, 2-7, 7-9, and over 9 landslides per 10 km^2, respectively (Table 3.8).

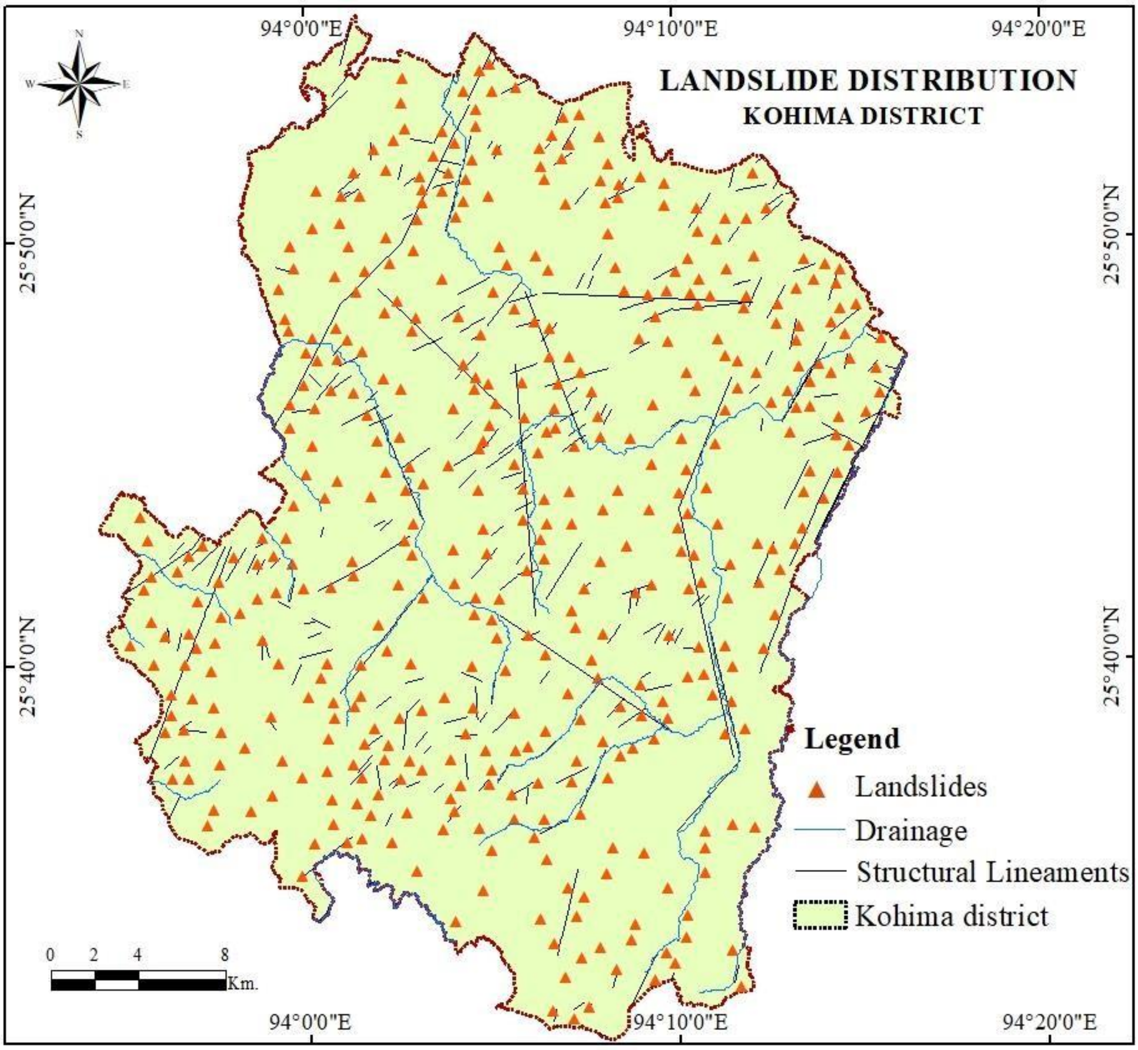


Figure 3.12: Spatial distribution of landslides in Kohima district, Nagaland.

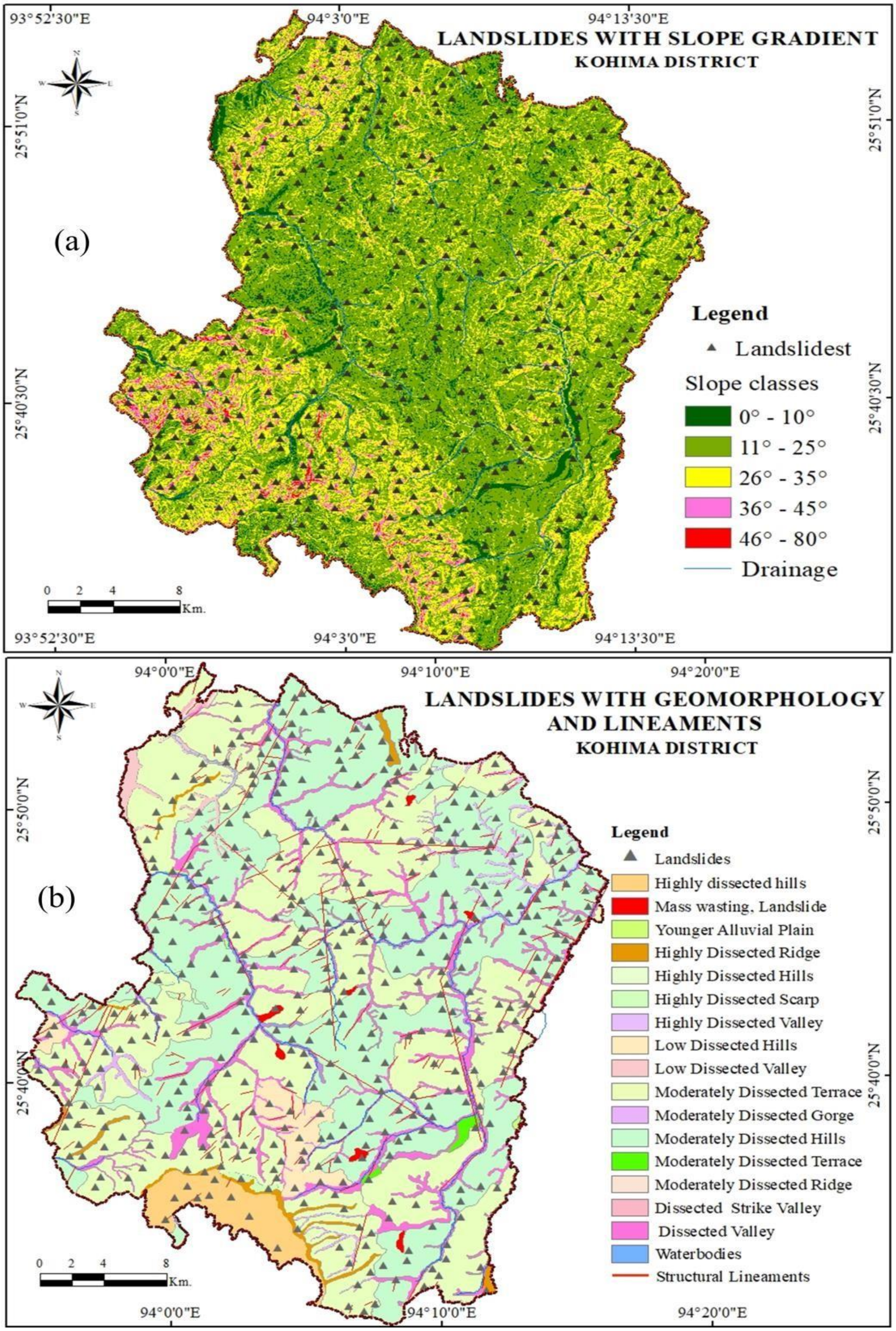


Figure 3.13: Spatial distribution of landslides with a) Slope gradient and b) Geomorphology and lineament of Kohima district, Nagaland.

Relief: The consideration of relief is a crucial aspect in the analysis of landslide hazards. The digital elevation model (DEM) of the region displays a wide range of diverse relief features. The elevation of the region ranges from 204 meters in the north to 2953 meters in the south, measured from mean sea level. This elevation has been divided into five categories: very low elevation (204-850 meters), low elevation (850-1650 meters), moderate elevation (1650-2400 meters), high elevation (1650-2400 meters), and very high elevation (1650-2400 meters) (Figure 2.2). The weight value of relief for the study region, as determined by the Analytical Hierarchy Process (AHP), is 0.038. The scale for the pairwise matrix is as follows: 3 for elevation below 824m, 6 for elevation between 825m and 1160m, 7 for height between 1161m and 1600m, 8 for elevation between 1601m and 2160m, and 9 for elevation beyond 2160m (Table 3.8).

Slope Aspect: Aspect refers to the orientation of slope faces in relation to the sun. It significantly impacts solar radiation, climate, rainfall, vegetation, and ground moisture. The slope aspect is crucial in determining the occurrence of landslides. The slope aspect map (Figure 2.4) of the study area was created using SRTEM DEM imagery with a resolution of 30m. It shows ten categories of slope aspects in a clockwise direction. These categories include flat (-1), north (0-22.50), northeast (22.5º-67.50º), east (67.5º-112.50º), southeast (112.50º-157.50º), south (157.50º-202.50º), southwest (202.50º-247.50º), west (247.50º-292.50º), northwest (292.50º-337.50º), and north (337.50º-360º). The weight value of the slope aspect for the research region, as determined by the Analytical Hierarchy Process (AHP), is 0.027. The pairwise matrix scale for distinct slope aspects ranges from 0 to 9, as shown in Table 3.8.

Land use pattern: The analysis of land use patterns plays a crucial role in determining the occurrence of landslides. The land use pattern (Dai and Lee 2002) directly influences the ongoing hydrological and geomorphic processes occurring on the earth's surface. In order to get a precise representation of the vegetation cover, which consists mostly of various types of forest land, shrub land, and farmland, a thorough mapping of the land use pattern was conducted. This involved using supervised classification of Landsat satellite images with a spatial resolution of 30m. This exercise demonstrates that the distribution of land use in the region is strongly influenced by geophysical factors such as relief, slope gradient, slope aspects, geology, and geomorphology, as well as biological factors such as rainfall, temperature, soil types, and water availability. The spatial distribution of land use and land cover indicates that woods and shrubs dominate the upslope areas, while urban and suburban areas, as well as agricultural land, are more prevalent in the downslopes and valleys (Figure

2.19). The land use map statistics are summarized in Table 2.6. The data suggests that approximately 82% of the study region's total area (978.96 km2) is comprised of natural landscape, which includes 18% dense forests, 63% open forest land, 0.39% water bodies, and 0.81% shrubs land. The remaining 18% of the area is classified as anthropogenic landscape, consisting of 9% build-up area, 1% wasteland, and 8% agricultural land. The weight value of the land use pattern for the research region according to the Analytical Hierarchy Process (AHP) is 0.019. The scale for the pairwise matrix is as follows: thick forest - 3, open forest - 4, agricultural - 5, built-up - 7, and barren land (wasteland) - 9 (Figure 2.19 and Table 3.8).

Soils: The research region has soils that originate from tertiary rocks, namely from two main lithological sections known as the Barail and Disang groups. The Barail group is composed of alternating layers of shales and sandstones, whereas the underlying Disang lithology consists of unfossiliferous shales, slates, and phyllites. A total of twelve soil types were identified and mapped in the research region based on geo-pedology taxonomy and soil attributes. These soil types were arranged in order of elevation, from lowest to highest, and were shown to be influenced by various geomorphological and lithological factors. Please refer to Table 3.9 for more details. The map (Figure 2.11) illustrates the spatial distribution of low relief geomorphology (Piedmonts, Foothills) which consists of Fine, Umbric Dystrochrepts soil and Fine, Loamy Lithic Udorthent soils. These soils are found over lithology composed of Disang group rocks, namely shales, slates, and phyllites. The moderate relief geomorphology in this area consists of upslope hills, downslope hills, terraces, and inter-hill valleys. The soils found here are mainly Fine Loamy Lithic Udorthent, Umbric Dystrochrepts, Fine Typic Paleudults, Typic Hapludults, and Fine-Loamy soils. These soils overlay the Disang group rocks, which include shales, slates, and phyllites. The high relief geomorphology consists of places with strike ridges, high relief structural hills, and high-middle structural hills. These areas are characterized by soils of Coarse-loamy, Typic Dystrochrepts, and Fine-loamy, Typic Dystrochrepts types. The underlying lithology is composed of Barail group rocks, namely shales and sandstone. The weight value of the land use pattern for the study region, as determined by the Analytical Hierarchy Process (AHP), is 0.015. The pairwise matrix scale for different types of soils spans from 1 to 9, as shown in Table 3.8.

Table 3.9: Landslide frequency, density and types under respective hazard zones in Kohima district, Nagaland

Landslide Hazard zones	Area		Landslide frequency	Landslide Density (in 10km^2)	Major forms of Landslide
	In Km^2	In %			
Low	176.21	18	9	1	Soil erosion and sedimentation
Moderate	362.22	37	88	2	Slumps, land fall, debris flow along rivers.
High	234.95	24	154	7	Active landslides, Debris flow, mass movement.
Very high	166.42	17	140	8	Old landslide cars, active landslides, rock fall and slop failure
Extreme	39.16	4	48	12	Old landslide cars, active landslides, rock fall and slop failure
Total area	978.96	100	439	4	All above

3.3.2. Spatial Variability of Landslide Hazard Zonation

The GIS layers of components that govern landslides were converted into raster format and classed. Each factor was assigned a pairwise matrix value ranging from 1 to 9, with 1 being the lowest significance and 9 representing the highest significance (Table 3.9). Subsequently, the classed raster GIS layers were combined using a weighted overlay operation in GIS software (ArcMap-10.8) to produce the final map of the landslide danger zone. The landslide hazard zone map illustrates five distinct degrees of landslide hazard potential within the Kohima region of Nagaland: low, moderate, high, very high, and extreme (Figure 3.15).

Areas of low landslide hazard: The regions with rolling to mild slope gradients (10 º-20º), such as the alluvial plain region in the northeast section, the piedmont zone, and youthful low-level river terrace land along valleys, have been identified as having the lowest susceptibility to landslides. These places have been classed as a low landslide hazard zone. This zone encompasses approximately 18% (176.21 km^2) of the district's total area (Figure 3.15 and Table 3.9). No significant landslide features are seen in this location, however, soil erosion and sedimentation originating from higher elevations are present (Table 3.9).

Areas of moderate landslide hazard: The regions with elevations ranging from 700m to 1200m, featuring slopes with a gradient of 20º to 30º, such as river valleys, midlevel river terraces, foothill zones, and downslope terrain, were recognized as zones with a moderate risk for landslides. This zone encompasses approximately 37% (362.22 km2) of the district's total area (Figure 3.14 and Table 3.9). The primary geomorphic elements associated to landslides in this area include river bank erosion, slumps, landfall, and debris flow, as indicated in Table 3.9.

Areas of high landslide hazard: Areas with elevations ranging from 700m to 1600m and moderate to steep slope gradients between 30º and 45º, such as high-level river terraces, erosion terraces, and moderately raised hills, have been recognized as zones with a high potential for landslides. This zone comprises approximately 24% (234.95 km2) of the district's total area (Figure 3.14 and Table 3.9). The capital city of the state, Kohima, is located inside this zone. The primary types of landslides in this area (Table 3.9) include active landslides, debris flow, and mass movement.

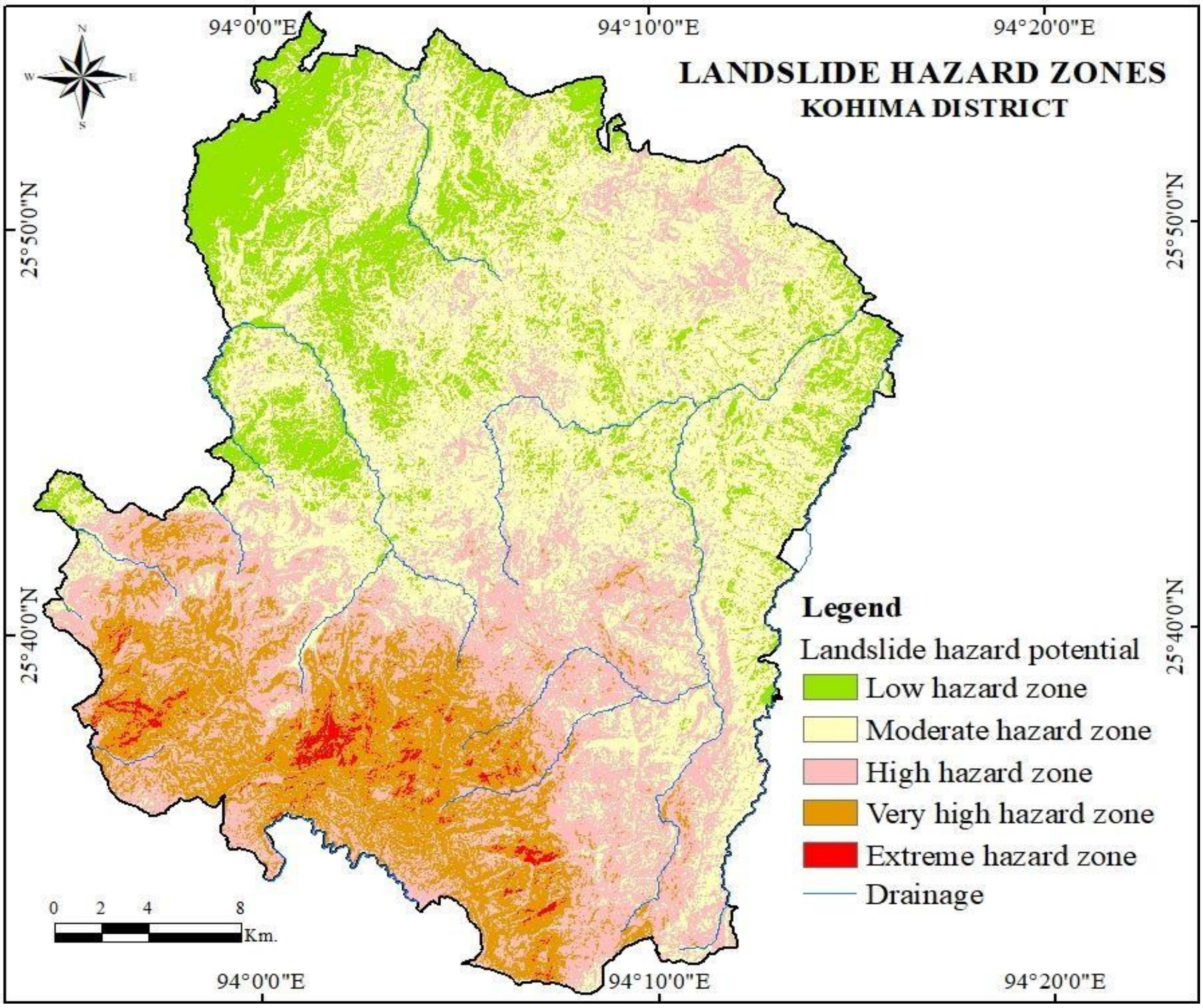


Figure 3.14: Spatial variability of landslide hazard zones of Kohima district, Nagaland.

Areas of very high landslide hazard: Zones of very high landslide danger have been identified in the southern half of the study region, characterized by high to very high elevation regions (1600m-2950m) with steep to very steep slope gradients (45º-80º). This zone encompasses approximately 17% (166.42 km2) of the district's total area. The capital city of the state, Kohima, is located inside this zone (Figure 3.14 and Table 3.9). The primary forms of landslide features in this area (Table 3.9) are old landslide scars, current landslides, rock falls, and slope failure.

Areas of extremely high landslide hazard: Within the region designated as the very high landslide hazard zone, there are some patches that exhibit a rather dark tone and texture. These patches indicate locations where landslides are now occurring, slopes are failing, significant erosion is taking place, and mass movement is happening. These areas are classified as the extremely high landslide hazard zone. From a geomorphological perspective, this zone consists of extensively eroded hilltop regions, steep valleys, and gorges that are characterized by ongoing tectonic activity and dynamic geohydrological processes. Approximately 4% (39.16 km2) of the whole area is classified as an extremely high landslide danger zone, as shown in Figure 3.14 and Table 3.9. The primary types of landslide features in this zone, as indicated in Table 3.9, are old landslide scars, active landslides, rockfalls, and slope failures.

3.4. Flash Flood Hazard Vulnerability of Kohima District

Flood dangers in downstream regions are caused by excessive rainfall and the resulting overflow from upstream areas (Brivio et al. 2002, Rawat et al. 2017, Bentivoglio et al. 2022). Floods are categorized as flash floods in hilly areas and river line floods in flat regions along the main stream, based on the characteristics and speed of water discharge (Rawat et al., 2012; Wang et al., 2015). A flash flood is a very destructive form of flooding that occurs in hilly areas and narrow valleys, providing very little time for advance warning. Researchers have identified several causes of flash floods worldwide, including incessant rainfall, rapid snow melt, glacial lake outburst, landslide dam outburst, and failure of dams in upstream areas. These events result in a significant amount of sediment being deposited into downstream river beds, reducing their carrying capacity. Consequently, water levels rise in the river, leading to overflow and the risk of river line floods in low-gradient areas or plains. Multiple contemporary studies have firmly established that flood disasters are increasing worldwide due to the detrimental effects of environmental degradation, such as deforestation (Bhattacharjee 2007, Bathurst 2011), changes in land use (Tollan 2002, Tiwari 2008), rapid urbanization (Rawat et al. 2017, Andreadis et al. 2022, Rentschler 2023), exploitation of natural resources (Cabrales 2019, Lampert 2019), global warming (Rawat et al. 2011, 2011a, 2017, Rawat 2014, 2017, Tabari 2020), and the impacts of anthropogenically accelerated climate change (Stott et al. 2010, Chan and Wu 2015, Magnan et al. 2021). The recent reports from the Intergovernmental Panel on Climate Change (IPCC) in 2022 reveal that in the Himalaya region, 45% of the total annual disasters consist of various types of floods and their associated geomorphic hazards, such as extreme erosion, mass movement, landslides, and debris flows. The remaining 55% is comprised of storms (23%), earthquakes (14%), epidemics (8%), extreme temperatures (6%), droughts (3%), and forest fires (1%). This report cautions that the frequency of flood events in the Himalaya region has been rising at an annual rate of 3-5%. As a result, the impacts of these floods, such as infrastructure damage, affected population, loss of human lives, and economic losses, have also increased (Orimoloye et al. 2021, Deshpande 2022, Alimonti and Mariani, 2023).

The Eastern region of the Himalayas is particularly prone to frequent floods and other hydrological hazards such as erosion, landslides, debris flow, and slope failure. This is primarily due to several factors including high-intensity annual rainfall ranging from 1600 to 3400mm, the presence of young and highly erodible rock formations mainly composed of sandstones, siltstones, and shales, fragmented reshaping geomorphology, high erodibility of soils, and significant surface and sub-surface runoff. These findings have been documented by Rawat et al. (2011, 2012, 2012a, 2012b), Das (2016), Shahiri (2016), and Barman et al. (2021). Every year, especially during the monsoon season, the community, socio-economy, wildlife, and environment in this area are increasingly affected by floods. These impacts have been documented by Aggarwal et al. (2017), Sattar et al. (2021), Byers et al. (2019), Das Deka (2021), Jibhakate (2023), Rudra (2014), Mohanty et al. (2020), Rawat et al. (2021), and Das (2016). In order to mitigate the effects of rising flood occurrences in the area, it is crucial to be adequately prepared before to the monsoon season. One aspect of this readiness is the mapping of flood hazard zones. It is crucial to create hazard maps in order to enable safe development activities by the government, community, and people. Considering this, Kohima district is also fairly affected by flash floods during the monsoon seasons. The region is extremely susceptible to flash flood hazards and related geomorphic hazards, including erosion, mass movement, landslides, and slope failure. This vulnerability is due to the rugged and steep terrain, active tectonic activity, fragmented young geology, dynamic reshaping of the landforms, and a high density of drainage network. It is crucial to consider that investigating flash flood hazard zones is necessary in order to adopt the necessary actions to reduce the risk.

3.4.1. Methodology

3.4.1.1. Thematic geospatial database development

The data provides comprehensive information on the geographical and attribute characteristics of geophysical, topography, hydro-meteorological, and biological elements that influence flash flood dangers. The data sources include studies conducted by Rawat et al. in 2011, 2012, 2014, 2017, and 2023. The geophysical parameters, including geology, geomorphic landforms, soil types, and drainage, were analysed using Survey of India (SOI) topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000 and Google Earth pictures at various resolutions. The topographic parameters, including relief pattern, slope gradient, slope aspect, topographic wetness index, flow accumulation, flow direction, drainage order, and drainage density, were studied using Digital Elevation Modelling (DEM) using NASA-STRM satellite images at a spatial resolution of 30 units. The study focused on hydrometeorological parameters, including rainfall and runoff data, which were analysed using secondary data obtained from various sources. Rainfall data spanning three decades (1991–2022) was obtained from the NASA Power Data Access Viewer (NASA-DAV: https://power.larc.nasa.gov/data-access-viewer/) and four ground-based meteorological observatories operated by the Indian Meteorological Department (IMD). The rainfall data collected from various sites was utilized to determine the average monthly and yearly rainfall. This data was then transformed into a raster layer using the inverse distance weighting (IDW) interpolation method to analyse the geographical distribution of rainfall. The present research incorporates runoff and soil erosion rate data obtained from recent investigations (Rawat et al. 2023). The study analysed ecological parameters, which included plant types and land use patterns, as well as infrastructure such as highways, local roads, and communication networks. The analysis was conducted using USGS-Landsat satellite images with a spatial resolution of 30 meters.

3.4.1.2. Analytic hierarchy process in GIS environment

The Analytical Hierarchy Process (AHP) introduced by Saaty (1980) is one of the most reliable, precise and widely used methods for extracting and quantifying subjective judgments in multi-criteria decision-making (MCDM), whereas performing this process in GIS environment through digital elevation modelling (DEM) has increased its credibility (Anand et al. 2022,).

3.4.1.3. Significance determination of flood causative factors: It is a first and most important task of AHP method to decide the significance of different flood triggering factors and then assign weight value accordingly. In the present study assigned weight values of each causative factor (thematic layers) and sub-factors (classes of thematic layers) of the flood hazard have been analyzed using this method. The assigned weight value ranges from 0-9 for different sub-factors or classes of thematic layers, where increasing weight value indicates more influence for flood occurrence (Table 3.10).

Table 3.10: Description of scales for pair comparison with AHP (Saaty, 1990)

Scales	Degree of preferences	Descriptions
1	Equally important	The contribution of the two factors is equally important
2	Intermediate value	In between two judgments
3	Slightly important	Experiences and judgment slightly tend to certain factor
4	Intermediate value	In between two judgments
5	Quite important	Experiences and judgment strongly tend to certain factor
6	Intermediate value	In between two judgments
7	Extremely important	Experiences and judgment extremely strongly tend to certain factor
8	Intermediate value	In between two judgments
9	Absolutely important	There is sufficient evidence for absolutely tending to certain factor

3.4.1.4. Development of pair-wise judgment matrix and overlay operation: Further to carry out the final flash flood hazard zone map, all vector layers of thematic GIS maps (causative factors) are converted and stored in a raster format to perform spatial overlay operation through a digital elevation model (DEM). Before overlay operation, the weight value of each factor and sub-factor is calculated through the AHP matrix in Microsoft Excel software which consists of a grid of an equal number of columns and rows, where scores are recorded on one side of the diagonal, whereas values of 1 are placed in the diagonal of the matrix (Saaty, 1990). To develop a pair-wise judgment matrix, each criterion has been rated against every other criterion by assigning a relative scale between 1 and 9 which is set based on diverse criteria and preferences as mentioned in Table 3.10. Subsequently, the weighted values of each criterion have been decided using AHP pairwise comparison matrix (Table 3.11).

Table 3.11: AHP pair-wise comparison matrix, weights, random index value and consistency ratio of spatial data (Saaty, 1990).

S.N.	Flood Causative Factors	Pairwise comparison matrix in between causative factors												Weights
		EL	RF	SG	TWI	DO	RB	DD	LU	GM	GL	ST	RO	
1	Elevation (EL)	1	2	3	4	5	6	7	8	9	10	11	12	0.296
2	Rainfall (RF)	1/2	1	2	3	4	5	6	7	8	9	10	11	0.218
3	Slope gradient (SG)	1/3	1/2	1	2	3	4	5	6	7	8	9	10	0.158
4	Wetness index (TWI)	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9	0.112
5	Drainage order (DO)	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	0.082
6	River buffers (RB)	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	0.059
7	Drainage density (DD)	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	0.052
8	Land use pattern (LU)	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	0.038
9	Geomorphology (GM)	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	0.027
10	Geology (GL)	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	0.021
11	Soil types (ST)	1/11	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	0.019
12	Runoff (RO)	1/12	1/11	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.016
Consistency ratio (CR)														0.047

Every row of pairwise comparison matrix values expresses the relative importance between the two criteria (Table 3.11). To examine whether the pairwise comparisons are consistent or not, the consistency ratio (CR) was calculated by applying the formula introduced by Kolat et al., 2012. Consistency ratio (CR) is an indicator of the degree of consistency or inconsistency (Chen et al. 2010; Feizizadeh and Blaschke, 2013). If the CR < 0.10, it indicates a good level of consistency in recognizing the class weights.

$$\text{Consistency Ratio (C.R.)} = \frac{\text{Consistency index (CI)}}{\text{Random Consistency Index (RI)}}$$

Consistency index (CI) = ßmax− n ⁄n−1

Where λmax represents the major eigenvalue and n is the number of factors.

RI is a Random consistency index, taken from a sample of randomly generated matrices, as suggested by Saaty, 1980.

The calculated consistency ratio (CR) in the present study stands at 0.046, which points out that the comparisons of characteristics are very consistent and the weights (Table 3.11) are suitable for spatial variability assessment of flash flood hazard.

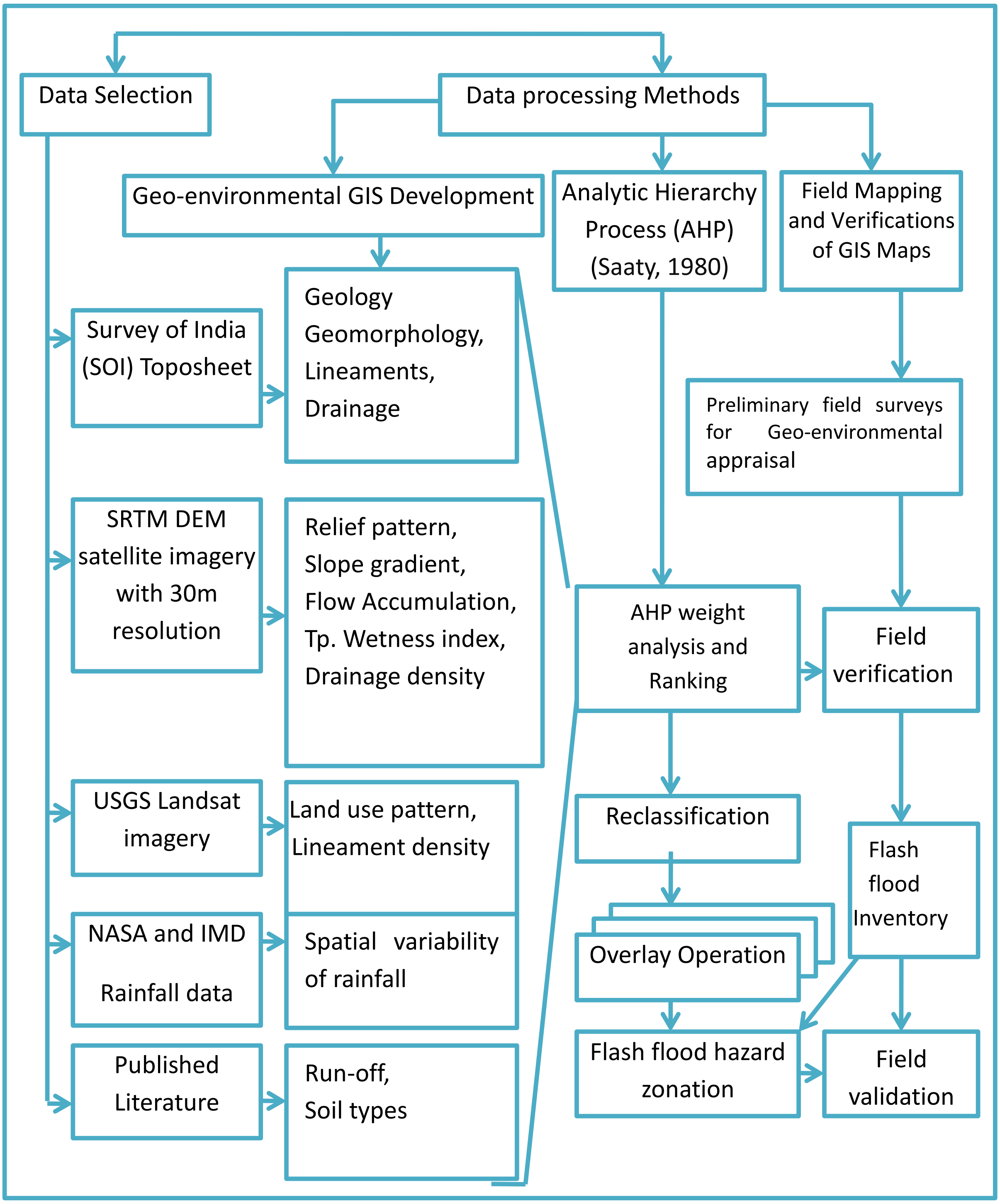


Figure 3.15: Methodology for flash flood hazard zonation in Kohima district, Nagaland

Table 3.12: Weights and rating matrix used for classification and overlay of GIS layers of flash flood causative factors and sub-factors.

No.	Factor	Classes	Rating	Weights
1	Elevation (in meters)	204-824	9	0.296
		825–1160	8	
		1161–1600	7	
		1601–2160	6	
		2161–2950	3	
2	Rainfall (in mm)	1620-1975	4	0.218
		1976–2260	5	
		2261–2488	6	
		2489–2703	7	
		2704–2919	8	
		> 3236	9	
3	Slope (in degree)	0–10	9	0.158
		10–25	7	
		25–35	5	
		35–45	3	
		45-80	1	
4	Topographic wetness index (TWI)	Very low	1	0.112
		Low	3	
		Moderate	5	
		High	7	
		Very high	9	
5	Drainage order	I-order	1	0.082
		II-order	2	
		III-order	4	
		IV-order	7	
		V-order	8	
		VI-order	9	
6	River buffer distance In meter (in meter)	0–500 (Core zone)	9	0.059
		500–1000 (Outer core zone)	7	
		1000–1500 (Intermediate zone)	5	
		1500–2000 (Outer zone)	2	
		>2000 (Remote zone)	1	

7	Drainage density (km/km^2)	< 2	1	0.052
		2–4	2	
		4–6	6	
		>6	8	
8	Land use pattern	Dense forest land	1	0.038
		Open forest land	3	
		Agricultural land	5	
		Built-up area	7	
		Waste land/barren land	9	
9	Geology	Tipam group	9	0.027
		Surma group	8	
		Disang group	6	
		Barail group	4	
10	Geomorphology	Alluvial plain	9	0.021
		Terraced land	8	
		Mid slope valleys	7	
		Piedmont zone	6	
		Low dissected hills	5	
		Moderately dissected hills	3	
		Highly dissected hills	3	
		Mass wasting sites/active landslides	6	
11	Soils	Fine–loamy Typic Dystrudepts	9	0.019
		Fine–loamy Typic Argiudolls	7	
		Fine–skeletal Cumulic Hapludolls	7	
		Coarse–loamy Pachic Dystrudepts	6	
		Fine–loamy Typic Paleudolls	5	
		Coarse–loamy Typic Hapludolls	5	
		Loamy–skeletal Typic Udorthents	4	
		Loamy–skeletal Entic Hapludolls	4	
		Loamy–skeletal Lithic Udorthents	4	
12	Runoff (l/s/km^2)	<10	2	0.016
		10–20	6	
		20–30	8	
		>30	9	

Elevation: The Analytical Hierarchy Process (AHP) weight value of relief for the study area stands at 0.296, whereas the scale for pairwise matrix stands 9, 8, 7, 6, and 3 for elevation below 824m, 825m-1160m, 1161m-1600m, 1601m-2160m and above 2160m respectively (Table 3.12).

Rainfall pattern: The Analytical Hierarchy Process (AHP) weight value of rainfall stands at 0.218, whereas the scale for pairwise matrix stands at 4, 5, 6, 7, 8 and 9 for annual average rainfall < 1975mm, 1976-2260 mm, 2261-2488mm, 2489-2703mm, 2709-2919mm, 2920-3236mm respectively (Table 3.12).

Slope gradient: The weight value of the slope gradient calculated through the Analytical Hierarchy Process (AHP) stands at 0.158 whereas the scale for pairwise matrix stands at 9, 7, 5, 3, and 1 for gentle, moderate, high, steep and very steep slopes respectively (Table 3.12).

Topographic wetness index: Topographic wetness index (TWI) is one the most important factors for hydrological studies, particularly groundwater augmentation, drought variability assessment, soil moisture depth assessment, runoff assessment and flood hazard assessment. In the present study, WTI was computed for spatial variability assessment of runoff and flood hazard. The computed value of the WTI rages from 1 to 5 across the study area, which has been categorized into five classes (Figure 3.16). The Analytical Hierarchy Process (AHP) weight value of TWI for the study area stands at 0.112, whereas the scale for pairwise matrix stands 1, 3, 5, 7, and 9 for topographic wetness index very low, low, moderate, high and very high (Table 3.12).

Drainage pattern and order: The digital elevation model (DEM) based drainage pattern map of the Kohima district shows 1 to 6 order streams across the study area. Figure 3.17 demonstrates the spatial distribution of drainage order which comprises 1 sixth-order river, 7 fifth-order rivers, 30 fourth-order, 139 third-order and thousands of second-orders to first-order. The Analytical Hierarchy Process (AHP) weight value of drainage order for the study area stands at 0.082, whereas the scale for pairwise matrix stands 1, 2, 4, 7, 8 and 9 for drainage order 1, 2, 3,4,5 and 6 respectively (Table 3.12).

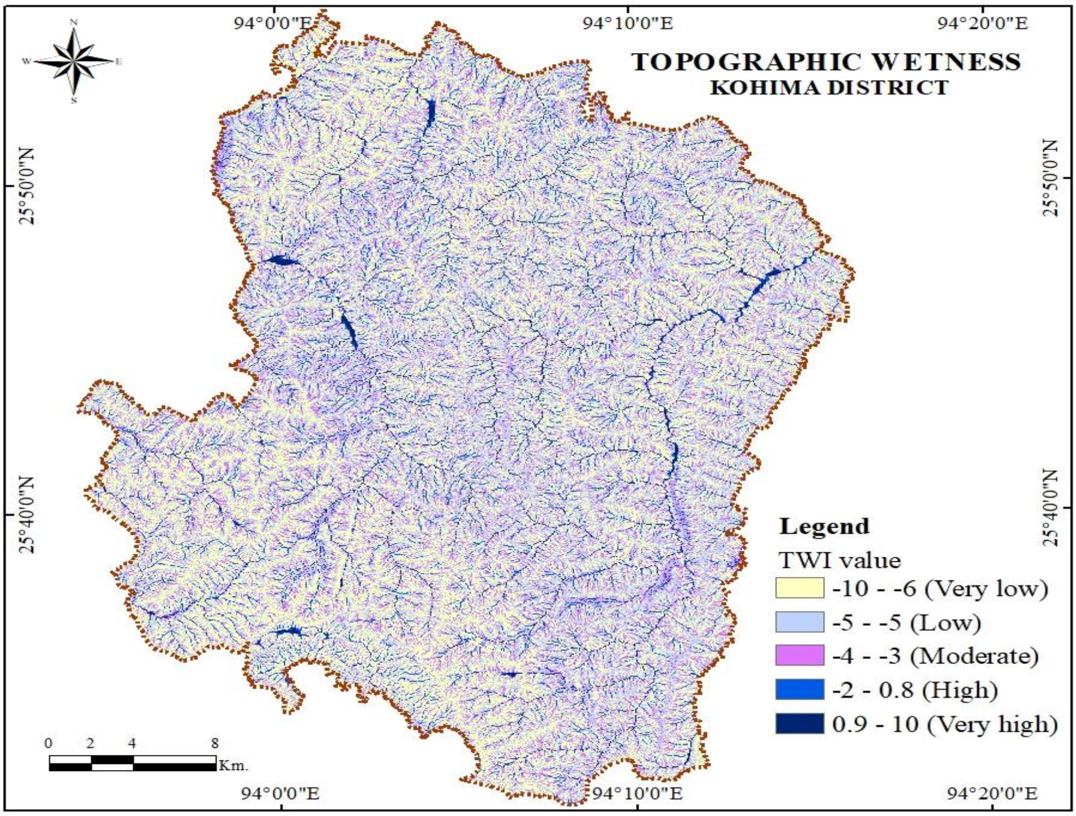


Figure 3.16: Spatial variability of topographic wetness index (TWI), Kohima district, Nagaland.

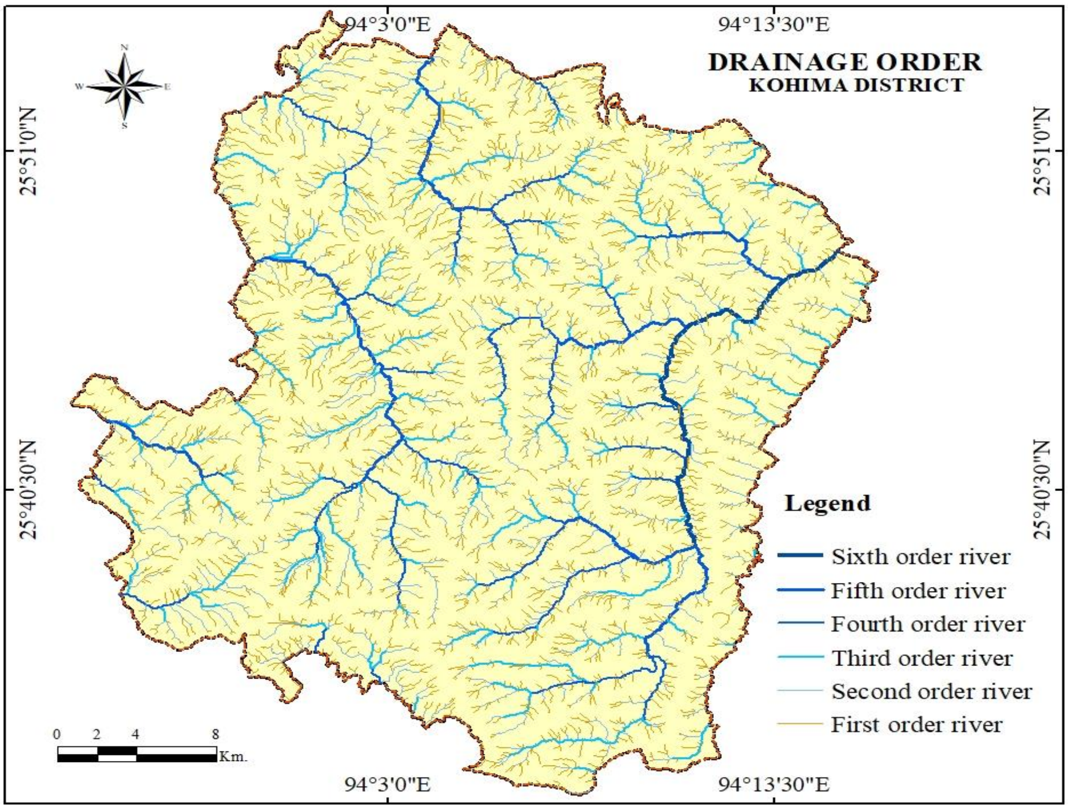


Figure 3. 17: Spatial distribution of drainage order in Kohima district, Nagaland.

River buffer zone: It is called Euclidean distance from the river to any location. The highest and second highest order rivers (fifth order and sixth order) of the study area were considered to carry out river buffer zones map. This map shows five buffer zones from the stream with a distance interval of 500 meters (Figure 3.18). The Analytical Hierarchy Process (AHP) weight value of river buffer zones for the study area stands at 0.059, whereas the scale for pairwise matrix stands 9, 7, 5, 2, and 1 for core zone, outer core zone, intermediate zone, outer zone and remote zone respectively (Table 3.12).

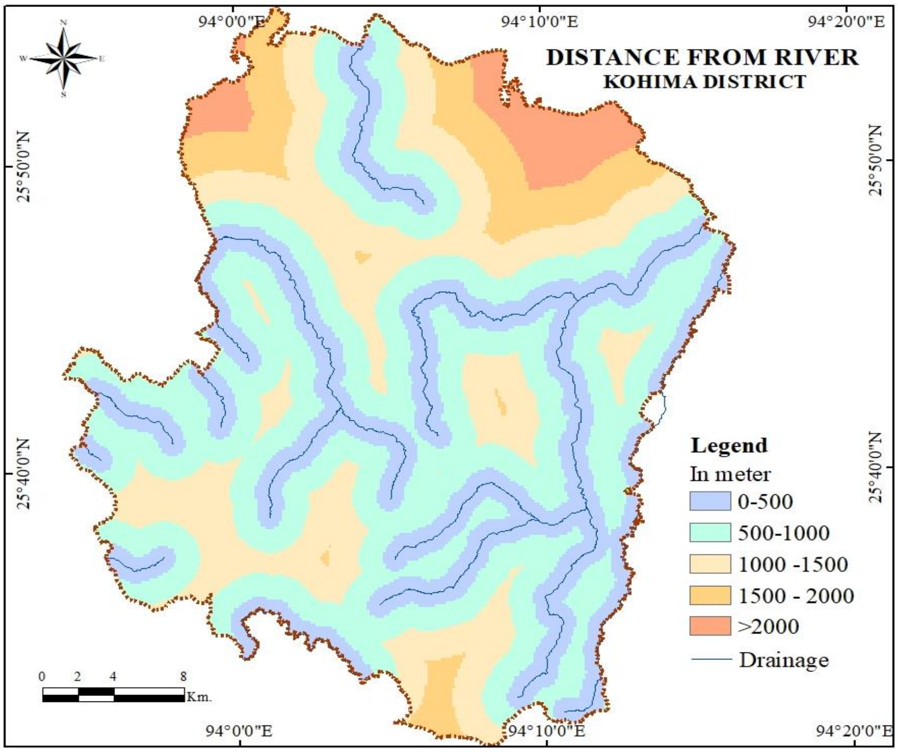


Figure 3.18: Spatial variability of drainage distance or buffer zone map of Kohima district, Nagaland.

Drainage density: It is one of the significant drivers of floods and associated geomorphic hazards such as erosion, mudflow, landslide, slope failure etc. The spatial variability of drainage density of the study area ranges from 1.5km/km^2 to 9km/km^2 which has been categorized into four different classes and assigned weight values to their significance to flood hazard (Figure 3.11). The Analytical Hierarchy Process (AHP) weight value of drainage density for the study area stands at 0.052, whereas the scale for pairwise matrix stands 1, 2, 6, and 8 for drainage density below 2, 2-4, 4-6 and above 6 km/km2 respectively (Table 3.12).

Land use pattern: The Analytical Hierarchy Process (AHP) weight value of the land use pattern for the study area stands at 0.038, whereas the scale for pairwise matrix stands at 1, 3, 5, 7, and 9 for dense forest, open forest, agricultural, built-up and barren land (wasteland) respectively (Table 3.12).

Geology: The Analytical Hierarchy Process (AHP) weight value of geology for the study area stands at 0.027, whereas the scale for pairwise matrix stands at 9, 8, 6, and 4 for lithology of Tipam group, Suma group, Disang group and Barail group respectively (Table 3.12).

Geomorphology: The Analytical Hierarchy Process (AHP) weight value of geomorphology for the study area stands at 0.021, whereas the scale for pairwise matrix ranges 1-9 for different types of landforms (Table 3.12).

Soils: The Analytical Hierarchy Process (AHP) weight value of the land use pattern for the study area stands at 0.019, whereas the scale for pairwise matrix ranges 1-9 under different types of soils (Table 3.12).

Runoff: The runoff thematic map is also one of the most significant factors. A recent study on runoff of Kohima district (Belho et al. 2023) has been implemented in the present study for flood hazard zone mapping of the region. This study has suggested three types of spatiotemporal runoff data, annual mean runoff rate, flood runoff rate, and base flow runoff rate. In the present study, the flood runoff rate has been included, which ranges from135 l/s/km2 to 689 l/s/km2 across the region and has been colorized into four zones, namely low, moderate, high and very high flood runoff zones (Figure 3.19). The Analytical Hierarchy Process (AHP) weight value of runoff for the study area stands at 0.016, whereas the scale for pairwise matrix stands 2, 6, 8, and 9 for low, moderate, high and very high runoff zone respectively (Table 3.12)

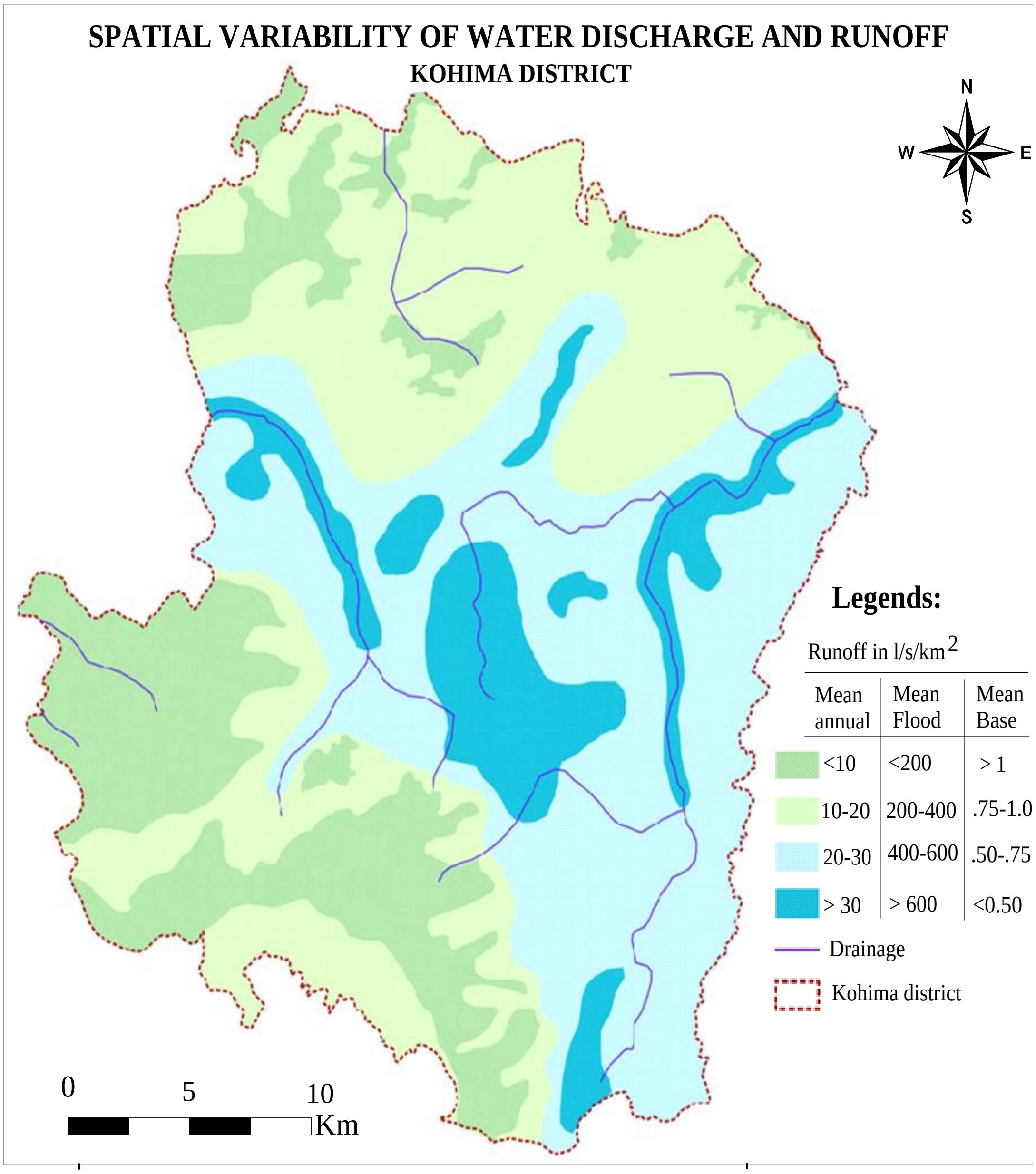


Figure 3.19: Spatial variability of runoff, Kohima district, Nagaland

3.4.2. Spatial variability of flash flood hazard zonation

All developed GIS layers of flash flood controlling factors were reclassified in raster format assigning pairwise matrix values which vary from 1-9 for the lowest to highest significant factor of landslide respectively (Table 3.13). Thereafter, to crop out the final hazard zone map, the reclassified raster GIS layers were superimposed by processing weighted overlay operation in GIS software (ArcMap-10.8). The flash flood hazard zone map demonstrates three levels of hazard potential across the Kohima district of Nagaland: low, moderate and high, (Figure 3.21). Further this map was validated through comprehensive fieldwork.

Table 3.13: Attribute data of flash flood hazard zones

Flood Hazard zones	Area		Geomorphological characteristics of respective hazard zone
	Km²	**%**	
Low	254.53	26	High to very high elevation strike ridge areas.
Moderate to high	597.17	61	River valleys, midlevel river terraces, foothill zones, down-slope land.
High to very high	127.26	13	Alluvial plain region in the northeast part, the piedmont zone, fluvial fans and young low level river terrace land along valleys.
Total area	**978.96**	**100**	**All above**

Areas of low to moderate flash flood hazard: Zones of very low flash flood hazard have been identified in high to very high elevation strike ridge regions (1600m-2950m), which are then followed by a dense network of first-order streams with steep to very steep slope gradients (44º-80º) (Figure 3.20 and table 3.13). This zone comprises approximately 26% (254.53 km2) of the district's total area, as indicated in Table 3.13.

Areas of moderate to high flash flood hazard: The regions with elevations ranging from 700m to 1200m, characterized by moderate to high slope gradients of 20º to 40º, such as river valleys, midlevel river terraces, foothill zones, and downslope land, were designated as zones with a moderate to high risk for flash floods. This information is depicted in Figure 3.20 and table 3.13. This zone encompasses approximately 61% (597.17 km2) of the district's total area. The primary geomorphic characteristics in this area include river bank erosion, slumps, landfall, and debris flow, as indicated in Table 3.13.

Areas of high to very high flood hazard: Third to sixth order river valleys flood plain area and the areas of rolling to gentle slope gradients (10 º-20º) such as the alluvial plain region in the northeast part, the piedmont zone, fluvial fans and young low-level river terrace land along valleys have been found high to very high susceptible to flash flood hazard (Figure 3.20 and table 3.13). This zone covers about 13% (127.26 km2) area of the district (Table 3.13).

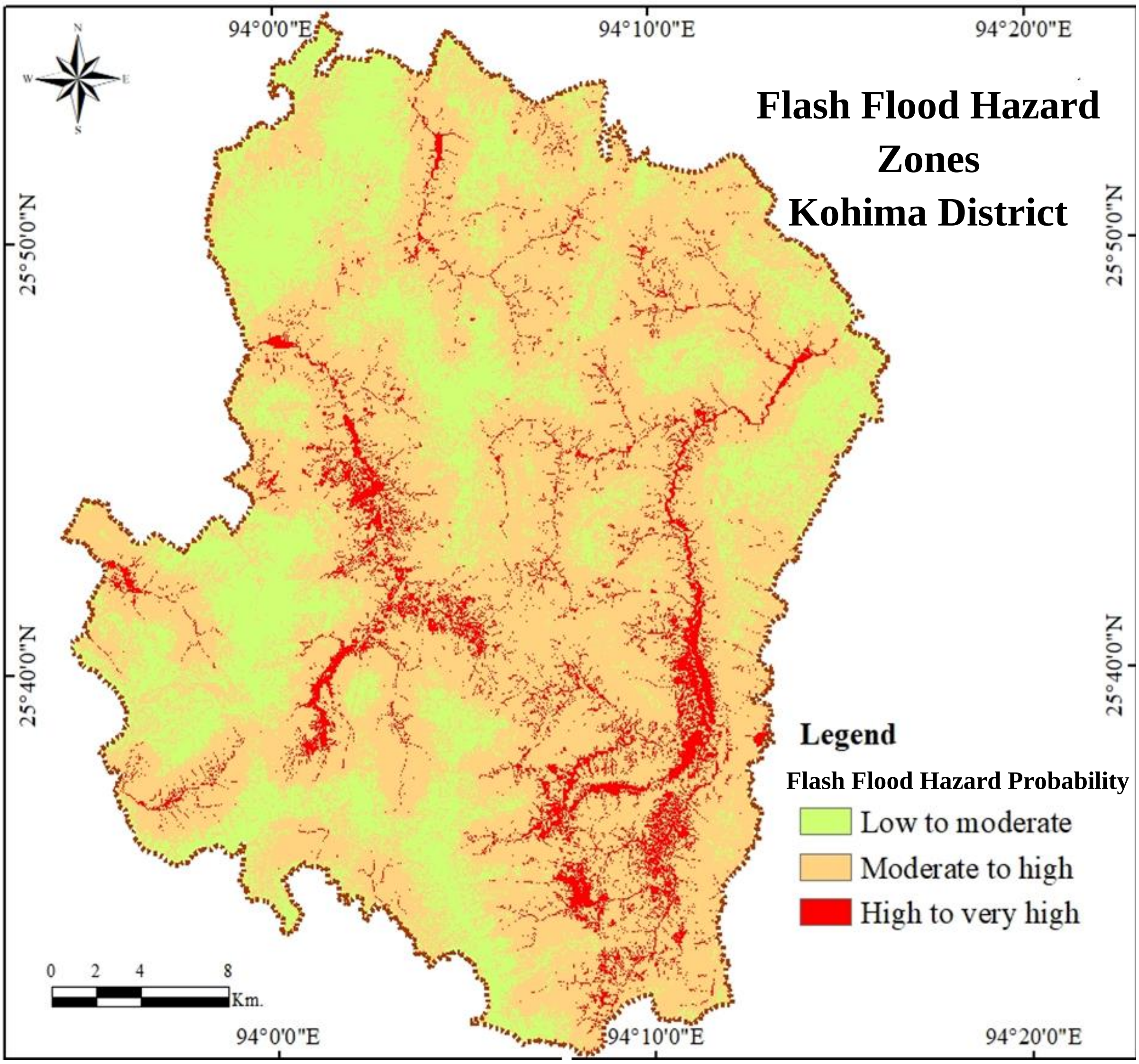


Figure 3.20: Spatial variability of flash flood hazard zones in Kohima district, Nagaland.

3.5. Watershed-wise Assessment of Geomorphic Hazards in Kohima district

Several streams and rivers, including the Sano ru in Kohima, Dzuna river in Kohima, and Sidzu river in Phek, encountered mudflow and landslides, resulting in significant debris obstructing the river flow. This situation poses a serious danger to the communities located downstream. In 2021, the recorded rainfall reached its lowest point, at roughly 1000 mm and witnessed a drought-like condition that had a significant impact on the agriculture industry. The Ministry of Science and Technology and Earth Science reported on December 1, 2021 that the state of Nagaland received 919.9 mm of rainfall during the monsoon season, which is 27% below the normal rainfall of 1261.8 mm, known as the Long Period Average (LPA).

Four specific watersheds, namely Dzuna ru, Charcha ru, Zachar ru, and Sano ru, have been chosen for examination. These four watersheds showcase distinct landscapes and land use patterns, representing the various types of landforms and land use found in and around the district. They also highlight the hydro-meteorological hazards experienced in the area, emphasizing the causes and effects to raise awareness about the threats posed by these hazards. This information aims to encourage the adoption of appropriate management practices in different parts of the district. Meteorological conditions have a major impact on Kohima district. Significantly, the continuous and substantial rainfall that occurs, especially during the monsoon seasons, hinders several operations due to the dangers it poses, such as flash floods and landslides in most instances. The study focused on analysing the impact of hydro-meteorological hazards on landforms and the surrounding environment in four different catchments. The analysis took into account the natural characteristics of each catchment and the level of human involvement it experienced. In light of this, conducting an evaluation and inventory of landscape hydrology across different ecological situations has been crucial for developing effective strategies to mitigate hazards and promote sustainable development.

3.5.1. Methodology

The study comprises mainly of two components, (a) lab/desk study and (b) field investigations. Litho-structural maps were prepared during field study, and details were verified and modified with other maps prepared during the lab and desk study.

3.5.1.1. Geo-ecological GIS Mapping

As a required primary data, GIS maps of geophysical parameters (comprised of geology, geomorphic landforms, topographic relief pattern, surface slope gradient, drainage morphometry, and soil characteristics) and ecological parameters (comprised of climate, vegetation cover and land use pattern) of the Kohima region was carried out using geospatial techniques. For carrying out this essential geospatial exercise, Indian Remote Sensing Satellite (IRS-1C) LISS III and PAN merged data, SRTM and Google Earth satellite data were geo-referenced and co-registered in the GIS environment using Survey of India topographical sheets (83G/13, 83G/14, 83K/1, 83K/2,83K/5) at scale 1:50000. As per the need, a combination of digital and visual interpretation techniques followed for the interpretation of geophysical and ecological features of the land surface on the satellite images.

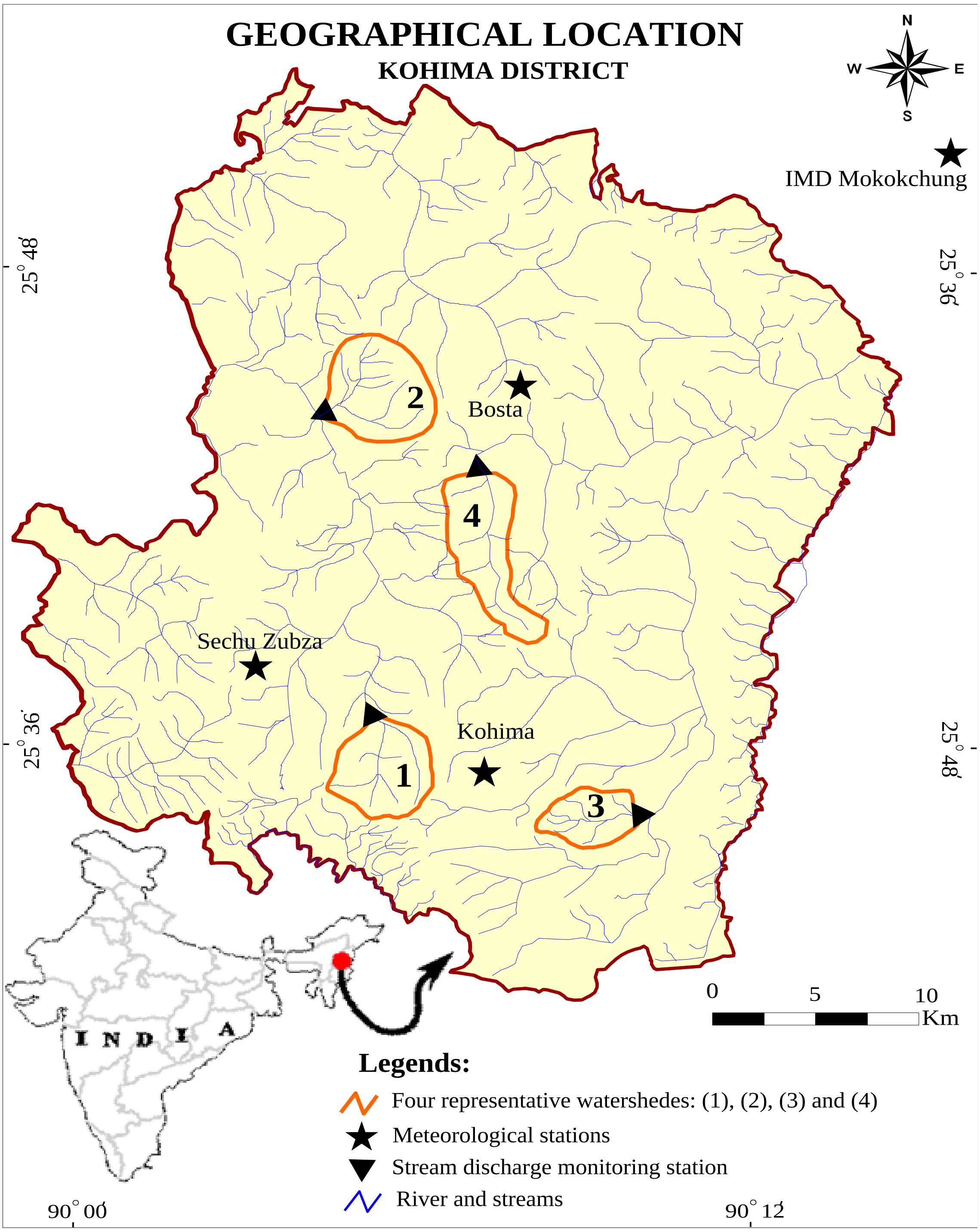


Figure 3.21: Geographical location of the study area with representative four experimental watershed in Kohima district, Nagaland.

3.5.1.2. Hydro-Meteorological Modelling

Hydro-meteorological modelling involves a thorough examination of meteorological factors including precipitation, temperature, humidity, and evaporation, as well as hydrological factors such as stream discharge, runoff, water balance, erosion, and sediment movement within a watershed. Four watersheds were selected for hydro-meteorological modelling in the Kohima eastern Himalaya area based on different geo-ecological circumstances (see Figure 3.21 and Table 3.14). The pigmy current meter method was used to measure the daily stream flow at the mouth of each representative watershed (Rawat, 2011; Rawat, 2013; Rawat, 2014; Rawat and Pant, 2016). In each of the sample watersheds in the region, a meteorological station was established at the highest height. This includes a Stevenson Screen equipped with a temperature/humidity recorder, a self-recording rain gauge, and a Pan-evaporation device. Four field assistants from the local community were assigned to each hydrological station to measure the flow of the river. They used a Pigmy Current Meter to collect daily discharge samples from the representative watershed. The average monthly discharge is calculated using the daily discharge data and evaluated using the formulae provided by Rawat in 2011 and 2013.

Stream Discharge = A X V (i)

Where;

A is cross-sectional area of the water channel and

V is Velocity of the water discharge

In order to do that, the discharge estimated in $m^3 second^{-1}$ is as follows:

Cross sectional area in $meter^{-2}$ X Velocity in meter $second^{-1}$ (ii)

Value of the water discharge in $m^3 second^{-1}$ was often used to calculate the runoff rate, as follows:

$$\text{Runoff Rate (in } m^3/s/\ km^2) = \frac{\text{Discharge } m^3 \text{ second}^{-1}}{\text{Total area of representative watershed } (km^2)} \quad \text{(iii)}$$

Runoff Rate in litre/second/km^2 = Runoff in $m^3/s/\ km^2$ X 1000 (iv)

Table 3.14: Geo-ecological characteristics and fragility of selected four sample representative watersheds

Representative Watersheds	**Geo-ecological characteristics of the representative sample watersheds**							**Geo-ecological status**
	Geology	**Geomorphic landforms**	**Relief pattern**	**Average slope**	**Climate**	**Land-use (Area in %)**	**Vegetation (Area in %)**	
1. Dzuna Ru (Fourth order)	Barail group: rained sandstone, silty shale and carbonaceous shale with minor coal seams	Rills, Gullies, active landslides over least dissected hills and Piedmont hill slope	1150-2364	35°	Temperate to humid temperate climate	-	Dense Forest: 100%	Unstressed
2.Charcha Ru (Fourth order)	Disang group: Dark to black carbonaceous, ferruginous, concretionary shales with a few interbeds of siltstones and sandstones	Moderately dissected hill slopes, Sites of debris Flow (Active Landslides their Cons, Fans)	540-1450	30°	Humid tropical climate	Roads: 2% Paths: 1% Crop land: 8% Settlements: 3%	Open forest:84% Scrubs land: 2%	Least stressed
3. Zachar Ru (Fifth order)	Disang group: Dark to black carbonaceous, ferruginous, concretionary shales with a few interbeds of siltstones and sandstones	Piedmont hill slope, Erosional Terraces, Fluvial fans, Bank Cut Area Moist area.	845-1620	25°	Humid subtropical climate	Crop land:78% Horticulture land: 17%:	Shrubs Land:5%	Moderately stressed
4. Sano Ru (Fourth order)	Disang group: Dark to black carbonaceous, ferruginous, concretionary shales with a few interbeds of siltstones and sandstones	Multilevel erosional terraces of piedmonts and dissected hills.	1145-1470	30°	Humid subtropical climate	Dense Urban land: 89% Crop land: 2%	Open forest:6% Scrubs land:3%	Most stressed

3.5.1.3. Runoff variability analysis and mapping

The spatial variability of runoff has been assessed and mapped out, considering all geophysical factors (including geology, geomorphic landforms, topographic relief pattern, surface slope gradient, drainage morphometry, and soil characteristics) and ecological factors (including climate, vegetation cover, and land use pattern) using the scalogram modelling approach. The scalogram modelling technique (Cruz, 1992) involved combining an arithmetic operation with numerical weights for the main components and sub-factors. This was done to obtain the Runoff Index (RI) for a given unit area.

To calculate the Runoff Index (RI) for the research region, we converted 6 primary variables that govern surface runoff and their 24 categories into weight maps. Each category of the key factors was assigned a specific weightage, as shown in Table 3.15. A comprehensive field and GIS mapping process has identified five significant factors: slope, relief geology, geomorphic features, land use pattern, and climate (including rainfall, temperature, evaporation, etc.).The climate factor was estimated through hydrometeorological modelling of four sample representative watersheds with different geo-ecological conditions. Each primary factor consists of five subordinate criteria that have been utilized to allocate weightage. The sub-causes are presented in Table 3.15, indicating that weights 1, 2, 3, and 4 correspond to low, moderate, high, and very high causative factors for runoff, respectively. The numerical weights of the sub-factors might vary and are determined depending on field experience and experimental research findings of a specific location. In this study, the Scalogram model, as proposed by Cruz in 1992, was utilized to examine the regional variability of runoff based on the components and sub-factors considered.

$$\text{RI (Score)} = \frac{[X1\ (An) + X2\ (An) + X3\ (An) + X4\ (An) + X5\ (An) + X6\ (An)}{Xn}$$

Where;

RI is Runoff Index,

X1, X2, X3, X4, X5 and X6 re major factors, respectively Slope, relief, geology, land use, geomorphology, climate, and land use pattern (Table 3.15), ‘An’ is total weight score (such as 1+2+3+4=10) of excising sub-factors or classes (A1, A2, A3, A4) of a major factor (Table 3.15),

Xn is total number of major factors (Table 3.15).

In order to do that, a spatial variability map of runoff was prepared following grid and isopleths technique (Wentworth, 1950 and Strahler, 1956) by using the weight value calculated by the above equation for each 0.25 km^2 grid. These accumulated weight values ranged from 6-24 throughout the study area and have been grouped into four zones, i.e., below 7, 7-14, 14-21 and above 21, respectively representing low runoff, moderate runoff, high runoff and very high runoff zones.

Table 3.15**:** Total 6 main factors (X) and their 24 sub-factors (A) have been considered as causative factors of Surface Runoff.

Sub Factors (A)	**Main factors (X) Geo-ecological Status**						**Geo-ecological Status**	**Weightage index**	**Runoff Potential**
	Slope Classes (X1)	**Relief Pattern (X2)**	**Geology or Litho-Units (X3)**	**Geomorphic Features (X4)**	**Climate (X5)**	**Land use/Land cover (X6)**			
A1	< 10°	<1000	Dark to black carbonaceous, ferruginous, concretionary shales	Rills, least dissected hills and Piedmont hill slope	Temperate to humid temperate climate	Dense Forest Land	Unstressed	1	Low
A2	10°-20°	1000-2000	Dark to black carbonaceous, ferruginous, concretionary shales	Moderately dissected hill slopes	Humid tropical climate	Open Forest land with shrubs	Least stressed	2	Moderate
A3	20°-30°	2000-3000	carbonaceous shale with minor coal seams	Piedmont hill slope, Erosional Terraces, Fluvial fans, Bank Cut Area Moist area.	Humid subtropical climate	Agricultural land, rural settlements	Moderately stressed	3	High
A4	>30	>3000	Grained sandstone, silty shale	Gullies, active landslides over least dissected hills and Piedmont hill slope.	Humid subtropical climate	Urban/suburban landscape	Highly stressed	4	Very High

Geo-ecological setup: Geo-ecological appraisal is essential for hydrological studies as it comprises key drivers of hydrological processes such as geology, geomorphology, relief pattern, slope gradient, terrain roughness, land use, vegetation, climate, etc. These key geo-ecological drivers of surface and sub-surface hydrology of the study region are being discussed here.

Geology: As mentioned earlier, the area experiences frequent seismic activity, which causes the physical displacement of lithological sections due to the immature, fractured, and decomposed character of the rocks (Figure 3.22 c). The region consists of four main lithological sections: Barail group, Disang group, Surma group, and Tipam group, arranged from south to north (Figure 3.22 c). The Barail group consists of coarse-grained sandstone, silty shale, and carbonaceous shale, with small coal seams present (Rajkumar et al., 2022). The Disang group consists of carbonaceous, ferruginous, concretionary shales that range in color from dark to black. It also contains a small number of interbeds of siltstones and sandstones (Srivastava, 2013). The Surma Group is composed of a series of alternating layers of shales, siltstones, sandy shales, and sandstones, occasionally interspersed with conglomerate beds (Holtrop and Keizer, 1970). The Tipam group comprises the Lakwa Sandstone, as documented by Bhandari et al. (1975) and Rawat (2004). The presence of multilevel river terraces, a high concentration of landslides (including rock fall, debris fall, creeping, and subsidence), slope failure, and fractured lithology along faults, thrusts, and significant fractures indicates that the area is geologically unstable and undergoes continuous changes.

Geomorphology: The region encompasses several secondary landforms at the local level, including those resulting from tectonic, fluvial, and pluvial processes. Based on the characteristics of geostructural lineaments, geological configuration, topography, slope, and drainage system at the regional scale, the study area can be classified as a fluvial river bed, alluvial fan, alluvial piedmont, multilevel dissected hills (low, moderate, high), and multilevel structural hills (low, moderate, high). Figure 3.22 (d) illustrates the geographical arrangement of several landforms in the Kohima district. The observable alteration in the land's physical features suggests that the area is in a state of instability, with new and more recent land formations such as fluvial fans, piedmont zones, and tectonic scars forming and modifying the landscape.

Relief: The Digital Elevation Model (DEM) accurately portrays the varied topography and slope features of the region. The relief ranges from 204m to 2953m above mean sea level and is divided into five divisions based on elevation, from lowest to tallest (Figure 3.22 a). Furthermore, in various terrain categories, the slope gradient ranges from 5° to 39° across the whole region (Figure 3.22 b). The range of slope gradients has been classified into four categories: gentle (<15°), moderate (15°-25°), high (25°-35°), and very steep (>35°). The regions with lower elevations (204-850 m), such as the main river basins, the alluvial plain region of Dimapur, and the over thrust zone of the 'belt of schuppen', which is mostly composed of shale and sandstone, are classified as gentle slope zones (<15°). These areas make up around 17% of the whole region. The moderate slope category (15°-25°) encompasses the mid-slope parts of the hill zone, which have an elevation ranging from 850 to 1650m. These areas occupy around 34% of the region's total area. The portion of the territory with an incline between 1650-2400m, ranging from 25°-35°, is referred to as the steep slope zone. This area accounts for 21% of the region. The hilltop area in the region is characterized by scarped valleys with vertical sides, which are governed by tectonic activity. This area has a very steep slope gradient, exceeding 35 degrees, and it occupies around 28% of the territory. Landslides are also common in this area.

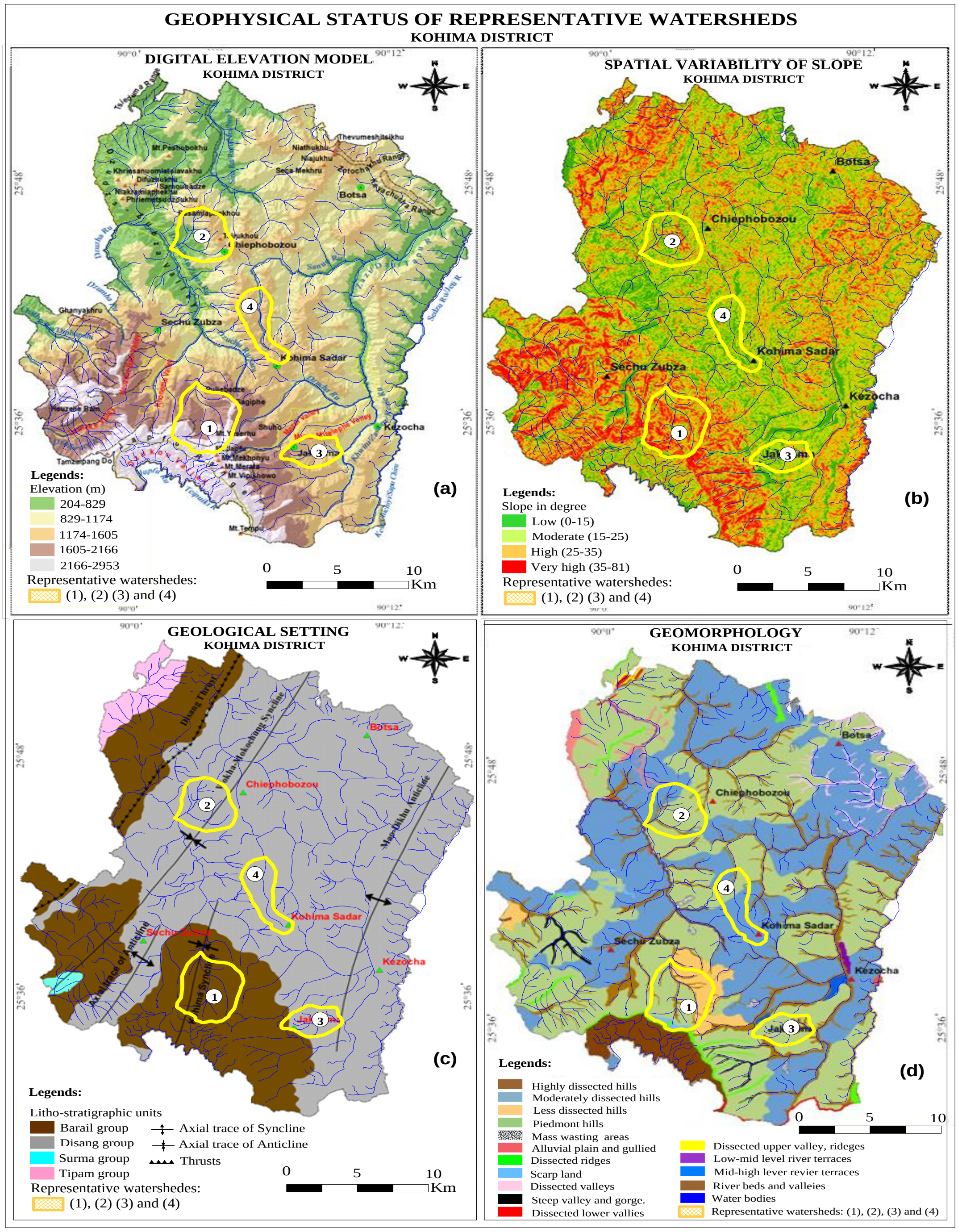


Figure 3.22: Geophysical status: a) relief, b) slope, c) geology and d) geomorphology of representative watersheds in Kohima district, Nagaland.

Climate: The study region exhibits spatial variability in meteorological characteristics across different elevations and slopes. This variability can be classified into four microclimatic zones: humid tropical (below 900m), humid subtropical (900m-1750m), humid temperate (1750m-2600m), and humid sub-temperate (2600m-3450m) (Figure 3.23). The annual average temperature ranges from less than 23ºC in the humid sub-temperate zone to more than

28⁰C in the humid tropical climatic zone. Similarly, the average precipitation varies from below 236 cm in humid tropical conditions to 324 cm in humid sub-temperate conditions.

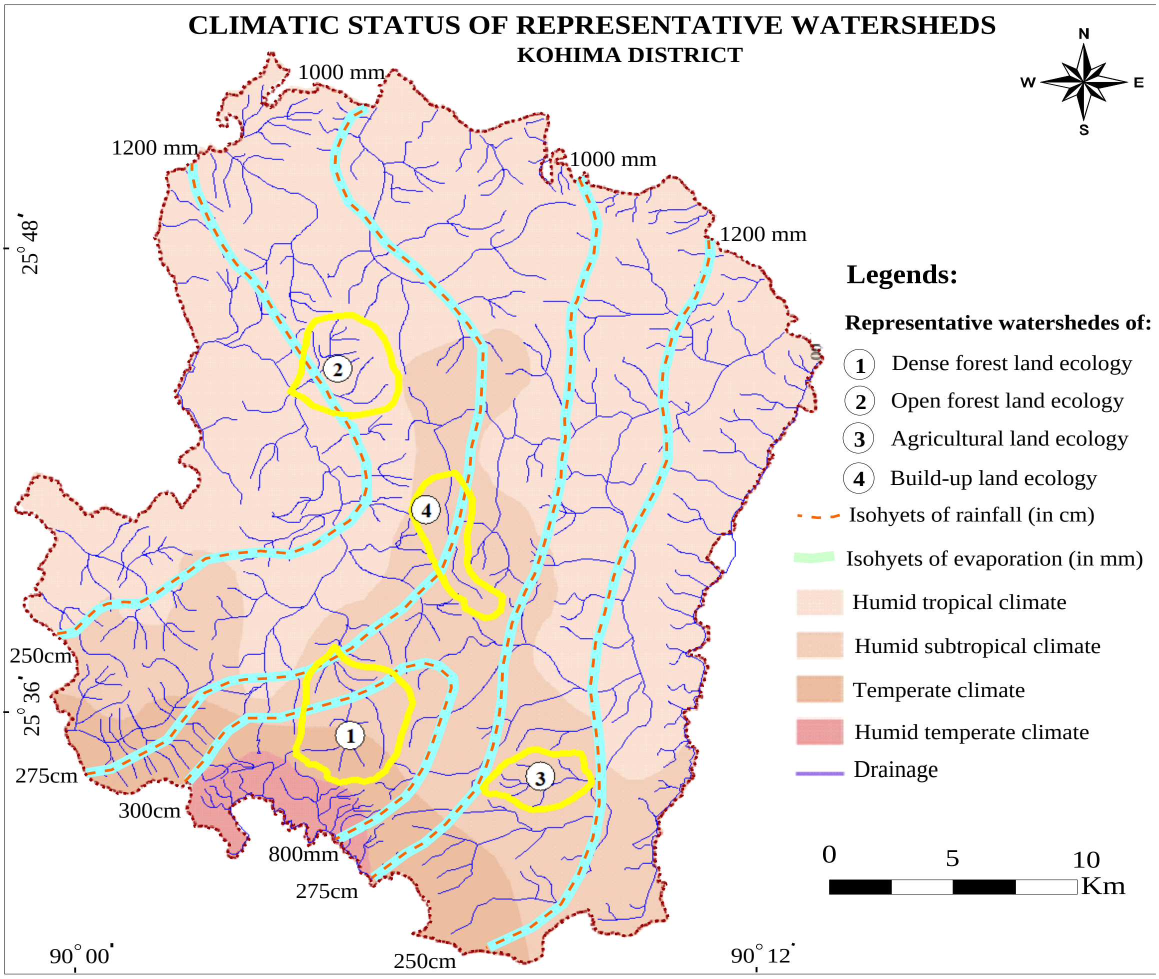


Figure 3.23: Climatic status of representative watersheds and Kohima district

Land use, land cover and vegetation pattern: The land use, land cover, and vegetation pattern of the region are primarily influenced by the geo-physical factors such as relief, slope gradient, slope aspects, geology, and geomorphology, as well as the ecological factors including rainfall, temperature, soil types, and water availability. The spatial distribution of land use and land cover indicates that the majority of the higher elevation regions are characterized by forest and shrub vegetation, while the lower slopes and valleys are predominantly occupied by urban and suburban areas, as well as agricultural land (Figure 3.24). The land use map statistics are summarized in table 3. The data suggests that out of the total area (978.96 km^2) of the study region, approximately 82% is covered by natural landscape. This includes 18% dense forests, 63% open forest land, 0.39% water bodies, and 0.81% shrubs land. The remaining 18% of the area is classified as anthropogenic landscape, which consists of 9% build-up area, 1% wasteland, and 8% agricultural land.

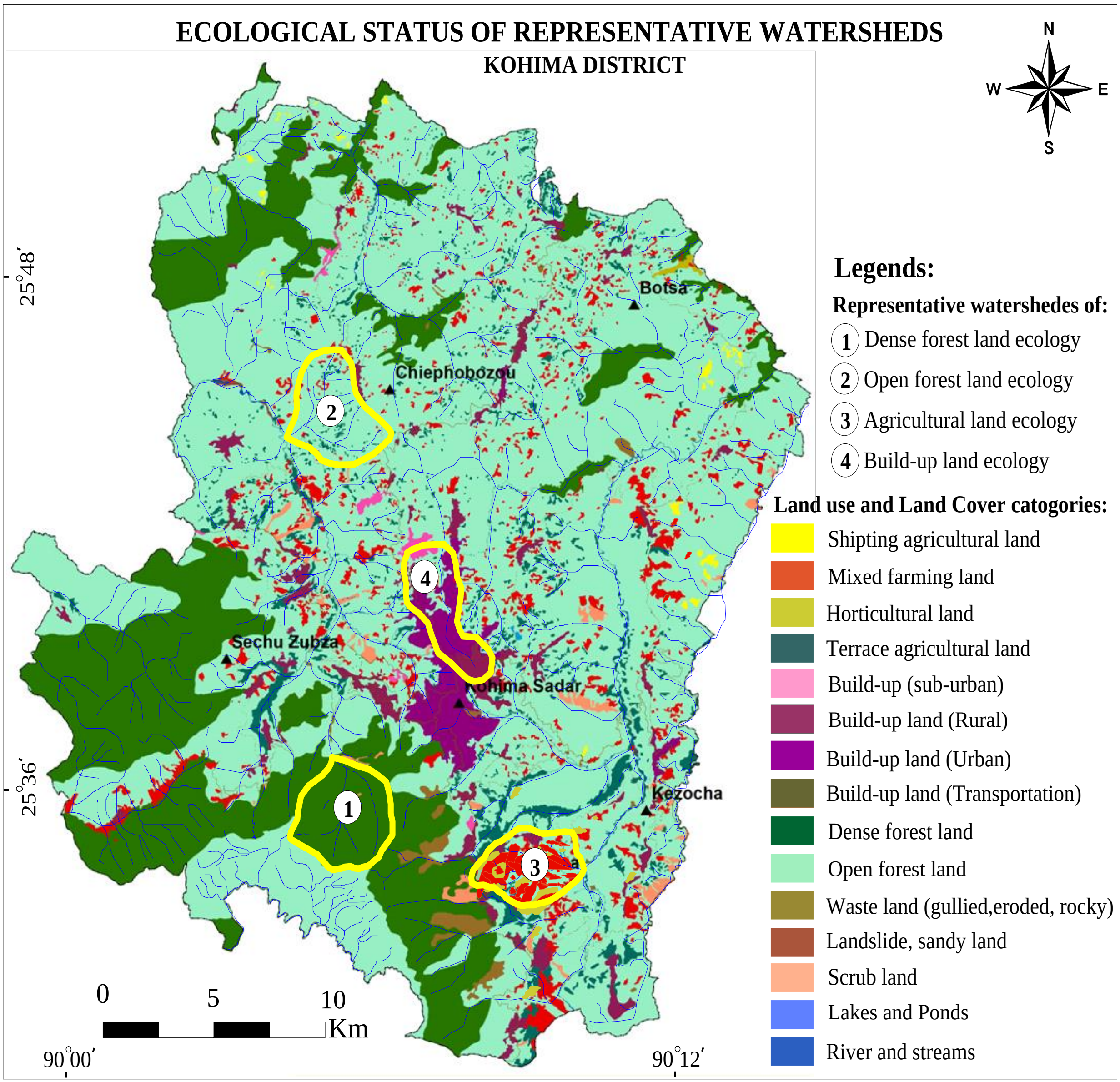


Figure 3.24: Ecological (land use, land cover and vegetation pattern) status of representative watersheds and Kohima district.

3.5.2. Stream discharge and runoff under varied geo-ecological system: The hydrological data from 2018 to 2022 for four specific watersheds were analysed and summarized. The results, presented in table 3.16, demonstrate significant variations in stream discharge (measured in $m^3/s/km^2$) based on the size of the respective catchment areas. In order to determine the effects of geo-ecological factors on watershed hydrology, the runoff data (expressed in $l/s/km^2$) was obtained by dividing the rate of stream discharge by the catchment area of the corresponding stream.

Mean Annual Runoff: The average annual water discharge rate or runoff for the landscape in Kohima district is 9.45 $l/s/km^2$. However, it may be as low as 8.23 $l/s/km^2$ in areas that are geologically untouched and not under stress such as the the Dzuna Ru representative watershed that has a dense forest area. In contrast, the Sano Ru representative watershed, which is under significant ecological stress, consists mostly of urban land has a runoff rate of 37.79 l/s/km^2. The Charcha Ru representative watershed, which consists of open forest area and experiences the least amount of geo-ecological stress, has a runoff rate of 13.02 l/s/km^2. On the other hand, the Zachar Ru representative watershed, which is predominantly agricultural land with rural communities, has a moderate level of stress and has a mean runoff rate of 21.76 l/s/km^2 (Table 3.16). Conversely, the average annual flood runoff rate in the Kohima region is 76.82 l/s/km^2. However, in the geologically pristine and unstressed areas, it may be as low as 20.49 l/s/km^2. The Dzuna Ru representative watershed consists of a dense forest area that experiences a maximum flood runoff of 307.28 l/s/km^2. On the other hand, the Sano Ru representative watershed is characterized by urban land and is geo-ecologically highly stressed. The Charcha Ru watershed, which represents open forest area and has the least amount of geo-ecological stress, has a flood runoff of 30.72 l/s/km^2. On the other hand, the Zachar Ru watershed, which represents agricultural land and rural villages, experiences a moderate level of stress and has a flood runoff rate of 76.82 l/s/km^2 (Table 3.16).

Table 3.16: Monthly rainfall, stream discharge, flood magnitude and surface runoff (mean runoff and flood runoff) of selected representative sample watersheds under varied geo-ecological conditions, based on five-year measurements (2018-2022).

(A) Representative watersheds	Geo-ecological Status	Hydro-meteorological Parameters	Monthly mean												Annual mean
			Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
(1) Dzuna Ru (21.758 km^2)	Unstressed Geo-ecology	Mean stream discharge (m^3/s)	0.04	0.08	0.11	0.17	0.24	0.45	0.40	0.29	0.17	0.10	0.08	0.03	**0.18**
		Mean stream discharge (l/s)	38	78	113	171	242	450	397	288	173	95	78	27	**179**
		Mean Runoff (l/s/km^2)	1.74	3.18	5.21	7.87	11.14	20.67	18.24	13.24	7.94	4.37	3.58	1.24	**8.23**
		Flood magnitude (m^3/s)	0.10	0.15	0.19	0.23	0.58	1.26	1.03	0.84	0.83	0.30	0.22	0.05	**0.45**
		Flood magnitude (l/s)	104	151	186	231	582	1264	1030	837	825	302	222	48	**446**
		Flood Runoff (l/s/km^2)	4.79	6.96	8.54	10.63	26.75	58.12	47.34	38.5	37.95	13.88	10.21	2.21	**20.49**
(2) Charcha Ru (24.350 km^2)	Least stressed Geo-ecology														
		Mean stream discharge (m^3/s)	0.04	0.12	0.17	0.38	0.48	0.83	0.73	0.50	0.30	0.17	0.07	0.03	**0.32**
		Mean stream discharge (l/s)	39	118	167	383	478	826	727	504	302	166	68	28	**317**
		Mean Runoff (l/s/km^2)	1.61	4.83	6.85	15.74	19.64	33.94	29.84	20.68	12.41	6.82	2.78	1.15	**13.02**
		Flood magnitude (m^3/s)	0.16	0.23	0.28	0.35	0.87	1.90	1.54	1.26	1.24	0.42	0.30	0.10	**0.67**
		Flood magnitude (l/s)	156	227	279	347	873	1896	1544	1256	1238	418	298	105	**668**
		Flood Runoff (l/s/km^2)	7.19	10.44	12.81	15.95	40.13	87.18	71.01	57.75	56.93	19.2	13.69	4.82	**30.73**
(3) Zachar Ru (10.465 km^2)	Moderately stressed Geo-ecology														
		Mean stream discharge (m^3/s)	0.01	0.03	0.14	0.29	0.39	0.56	0.49	0.41	0.25	0.14	0.03	0.01	**0.23**
		Mean stream discharge (l/s)	10	30	143	285	388	556	494	411	246	136	26	7	**228**
		Mean Runoff (l/s/km^2)	0.95	2.86	13.68	27.27	37.07	53.15	47.21	39.24	23.54	12.95	2.52	0.68	**21.76**
		Flood magnitude (m^3/s)	0.39	0.57	0.70	0.87	2.18	4.74	3.86	3.14	3.10	0.94	0.64	0.32	**1.67**
		Flood magnitude (l/s)	391	568	697	867	2182	4740	3861	3140	3095	938	638	316	**1671**
		Flood Runoff (l/s/km^2)	17.96	26.1	32.03	39.86	100.31	217.95	177.53	144.38	142.31	43.11	29.35	14.54	**76.82**
(4) Sano Ru (23.426 km^2)	Highly stressed Geo-ecology														
		Mean stream discharge (m^3/s)	0.01	0.04	0.88	1.33	1.49	1.98	1.76	1.58	0.95	0.52	0.06	0.01	**0.89**
		Mean stream discharge (l/s)	14	42	884	1332	1493	1981	1760	1581	948	522	55	10	**885**
		Mean Runoff (l/s/km^2)	0.60	1.81	37.74	56.87	63.75	84.56	75.14	67.48	40.49	22.27	2.36	0.43	**37.79**
		Flood magnitude (m^3/s)	1.56	2.27	2.79	3.47	8.73	18.96	15.44	12.56	12.38	3.54	2.34	1.26	**6.68**
		Flood magnitude (l/s)	1563	2271	2786	3468	8727	18962	15445	12561	12381	3539	2341	1265	**6683**
		Flood Runoff (l/s/km^2)	71.85	104.4	128.1	159.45	401.25	871.8	710.1	577.5	569.25	162.7	107.65	58.15	**307.28**
(B) Kohima District (Average)	Moderate to highly stressed Geo-ecology														
		Mean stream discharge (m^3/s)	0.00	0.01	0.22	0.33	0.37	0.50	0.44	0.40	0.24	0.13	0.02	0.00	**0.22**
		Mean stream discharge (l/s)	3.50	10.50	221.00	333.00	373.25	495.25	440.00	395.25	237.00	130.5	13.75	2.50	**221.25**
		Mean Runoff (l/s/km^2)	0.15	0.45	9.44	14.22	15.94	21.14	18.79	16.87	10.12	5.57	0.59	0.11	**9.45**
		Flood magnitude (m^3/s)	0.39	0.57	0.70	0.87	2.18	4.74	3.86	3.14	3.10	0.89	0.59	0.32	**1.67**
		Flood magnitude (l/s)	391	568	697	867	2182	4741	3861	3140	3095	885	585	316	**1671**
		Flood Runoff (l/s/km^2)	17.96	26.10	32.03	39.86	100.31	217.95	177.53	144.38	142.31	40.68	26.91	14.54	**76.82**
		Rainfall (mm)	**13**	**39**	**95**	**185**	**329**	**517**	**393**	**350**	**240**	**172**	**43**	**7**	**2382**

Mean monthly flow: It is the average of five years of aggregated monthly discharge data (Table 3.16). The monthly discharge hydrograph demonstrates that it varies in accordance with the rainfall patterns throughout the course of the year (Figure 3.25). December is the month when the stream's water level is at its lowest owing to a lack of rainfall. This is known as the base flow of streams (Table 3.16). The months from January to April represent the ascending portion of the hydrograph. During this season, the water outflow rises in direct proportion to the increase in rainfall. June is the month that the watershed releases water at its highest level of discharge. From July to November, the hydrograph experiences a recession section characterized by a progressive drop in stream flow.

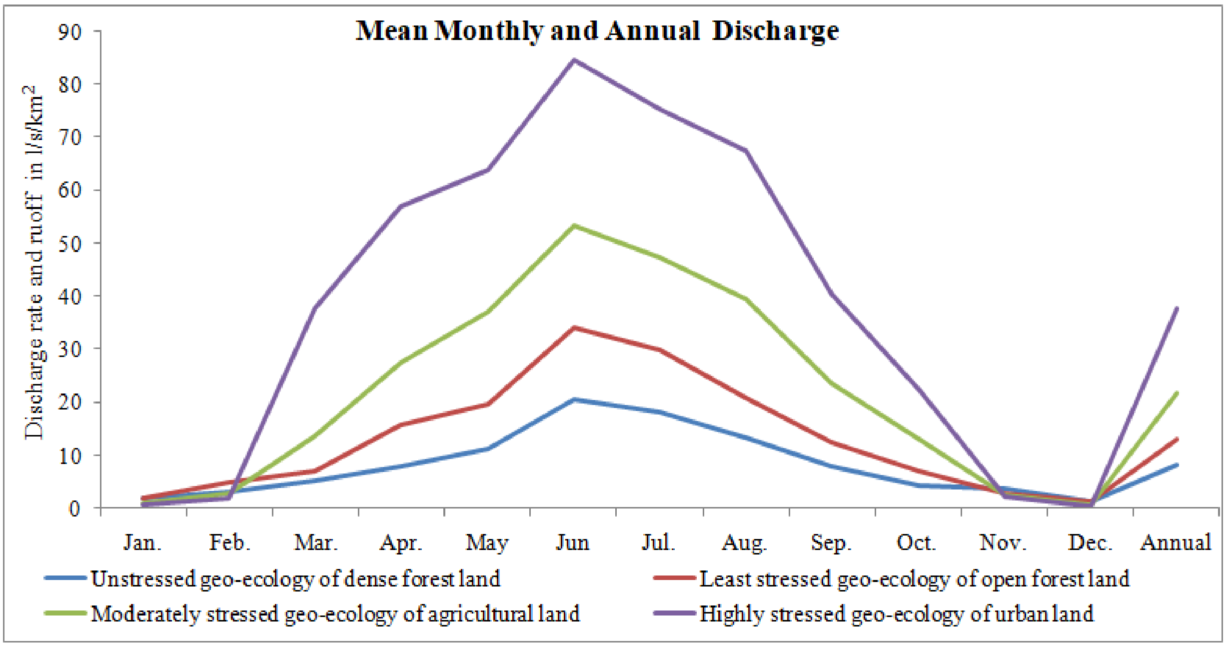


Figure 3.25**:** Hydrograph of mean monthly and annual discharge and runoff under varied geo-ecological system of the four watersheds.

Base flow: It is the lowest and leanest discharge rate of the streams during the early winter season (November to January) particularly in the month of December. Table 3.16 depicts that the average rate of base flow in Kohima district stands at 0.11 l/s/km^2 whereas it has wide variations depending upon geo-ecological conditions of the areas (Figure 3.26).Geo-ecologically virgin and unstressed Dzuna Ru representative watershed of dense forest land, accounts maximum rate of base flow (1.24 l/s/km^2) and geo-ecologically most stressed Sano Ru representative watershed of urban land accounts minimum base flow (0.43 l/s/km^2) whereas geo-ecologically least stressed Charcha Ru representative watershed of open forest land and moderately stressed Zachar Ru representative watershed of agricultural land along with rural settlements accounts 1.15 l/s/km^2 and 0.68 l/s/km^2 base flow rates respectively.

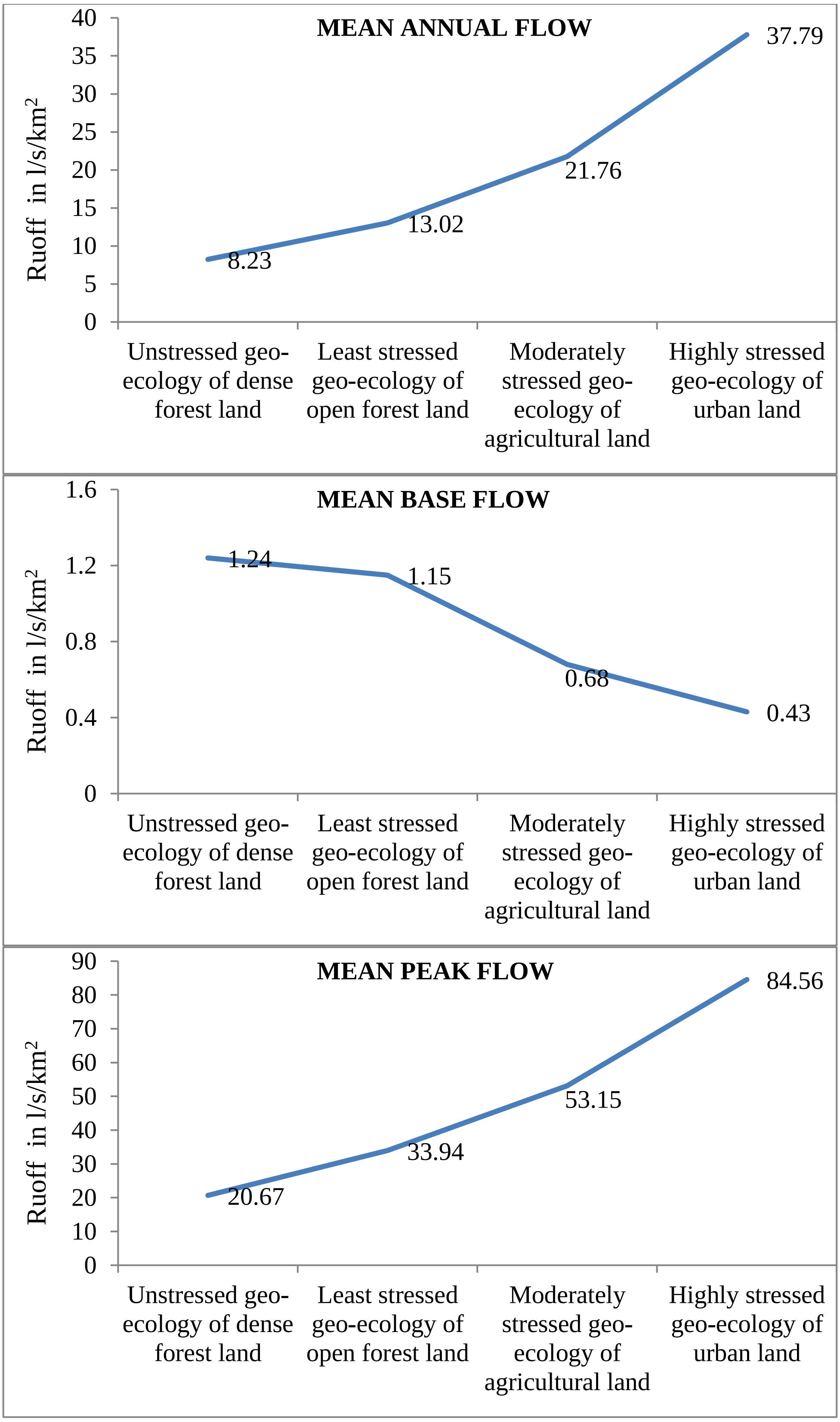


Figure 3.26**:** Hydrograph of mean annual, mean base and mean peak discharge and runoff under varied geo-ecological system.

Peak flow: It is the highest discharge rate of the streams during the summer to rainy season particularly in the month of June (Table 3.16). The peak flow hydrograph (Figure 3.26) for the month of June depicts that the average rate of peak flow in Kohima district stands at 21.14 l/s/km^2 whereas it varies at a minimum 20.67 l/s/km^{2}in geo-ecologically virgin and unstressed Dzuna Ru representative watershed of dense forest land to maximum 84.56 l/s/km^2 in geo-ecologically most stressed Sano Ru representative watershed of urban land. Whereas geo-ecologically least stressed Charcha Ru representative watershed of open forest land and moderately stressed Zachar Ru representative watershed of agricultural land along with rural settlements accounts 33.94 l/s/km^2 and 53.15 l/s/km^2 peak flow rates respectively.

Flood magnitude flow: It is an event-based short-time extreme discharge rate of the streams during incessant rainfall hours particularly in the month of June (Table 3.16). The flood magnitude hydrograph depicts that the average rate of flood magnitude in Kohima district stands at 76.82 l/s/km^2 whereas it varies minimum of 58.12 l/s/km^2 in geo-ecologically virgin and unstressed Dzuna Ru representative watershed of dense forest land to maximum 871.80 l/s/km^2 in geo-ecologically most stressed Sano Ru representative watershed of urban land. Whereas geo-ecologically least stressed Charcha Ru representative watershed of open forest land and moderately stressed Zachar Ru representative watershed of agricultural land along with rural settlements accounts for 87.18 l/s/km^2 and 217.95 l/s/km^2 peak flow rate respectively.

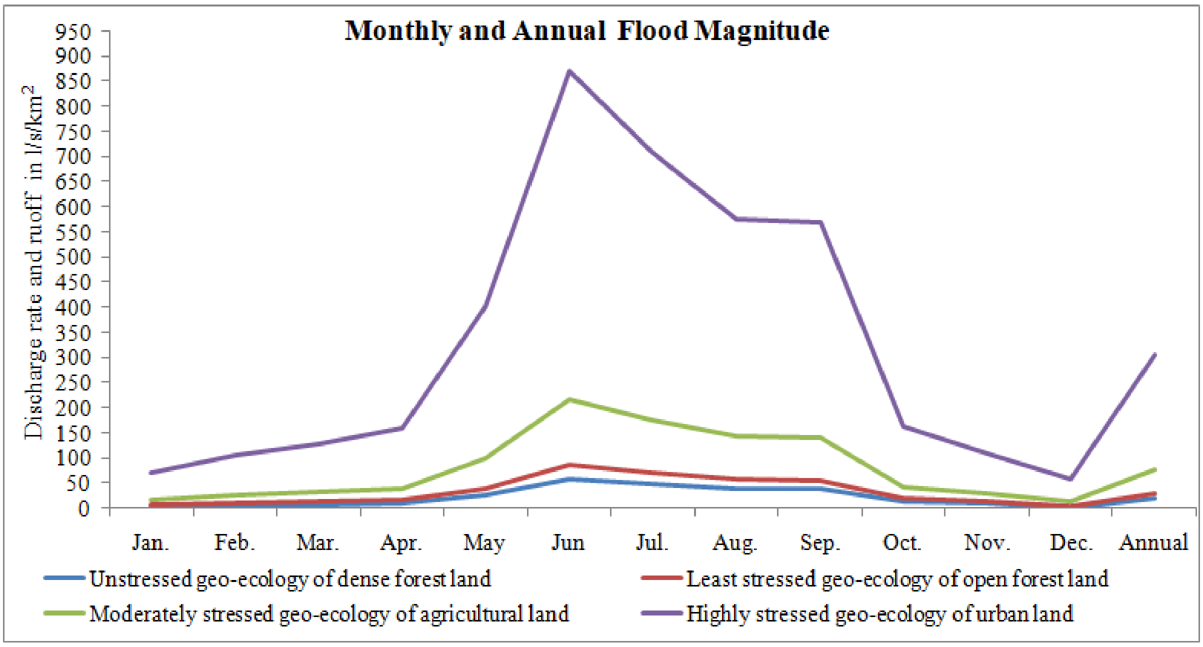


Figure 3.27**:** Hydrograph of monthly and annual flood magnitude varied geo-ecological system

3.5.3. Spatial variability of runoff

To carry spatial variability of runoff, the discharge data of representative watersheds implemented along with other runoff controlling factors through scalogram modeling approach (Cruz, 1992), approach (Cruz, 1992) (Table 3.15). The spatial variability of surface runoff suggests four zones: low, moderate, high and very high runoff zones (Figure 3.19).

Low runoff zone: Geo-ecologically least to unstressed landscape (comprising Barail group rocks, gentle slopes between below 20°, sites of Rills, least dissected hills and Piedmont hill slope geomorphology; temperate climatic characteristics; dense forest land use category) are under low runoff (below 10 l/s/km^2 annual mean).But during peak floods particularly in the month of June, the runoff rate rises up to 58.12 l/s/km^2 (Table 3.17).Out of the total area (978.96 km^2) of the Kohima district**,** 18% (176.21km^2) is under a low runoff zone (Figure 3.19)

Table 3.17: Runoff zone of Kohima district in Nagaland (India)

Runoff zones	Accumulated Runoff index	Runoff l/s/km^2		Area covered	
		Mean Annual	Flood magnitude	Km^2	%
Low	Below 7	Below 10	Below 200	176.21	18
Moderate	7 – 14	10 –20	200 – 400	313.27	32
High	14 – 21	20–30	400 –600	401.37	41
Very High	Above 21	Above 30	Above 600	88.11	9
Total	**-**	**-**	**-**	**978.96**	**100**

Moderate runoff zone: Geo-ecologically moderate to least stressed landscape (comprised of Disang group rocks, moderate slopes between 10°-20°, sites of moderately dissected stable hill slope geomorphology; temperate climatic characteristics; open forest with dense shrubs land use category) are under moderate runoff (10-20 l/s/km^2 annual mean).But during peak floods particularly in the month of June, the runoff rate rises up to 87.18 l/s/km^2 (Table 3.17).Out of the total area (978.96 km^2) of the Kohima district**,** 32% (313.27 km^2) is under a moderate runoff zone (Table 3.17 and Figure 3.19).

High runoff zone: Geo-ecologically high to moderately stressed landscape (comprised of Disang group and Barail group rocks, steep slopes between 20°-30°, sites of Piedmont hill slope, Erosional Terraces, Fluvial fans, Bank Cut Area Moist area geomorphology; humid temperate climatic characteristics; agricultural, horticultural and barren land use category) are under high runoff (20-30 l/s/km^2 annual mean). But during peak floods particularly in the month of June, the runoff rate rises up to 217.95 l/s/km^2 (Table 3.17). Out of the total area (978.96 km^2) of the Kohima district**,** 41% (401.37 km^2) is under a high runoff zone (Table 3.17 and Figure 3.19).

Very High runoff zone: Geo-ecologically most stressed landscape (comprises Barail group rocks, very steep slopes above 30°, sites of gullies, active landslides over least dissected hills and Piedmont hill slope geomorphology, humid subtropical climatic characteristics, urban and suburban land use pattern) are under very high runoff (above 30 l/s/km^2 annual mean). However, during peak floods particularly in the month of June, the runoff rate rises up to 871.80 l/s/km^2 (Table 3.17). Out of the total area (978.96 km^2) of the Kohima district**,** 9% (88.11km^2) is under a very high runoff zone (Table 3.17 and Figure 3.19).

References

Abdo, H., & Salloum, J. (2017). Spatial assessment of soil erosion in Alqer-daha basin, Syria. *Model Earth Syst Environ* 3:26

Ader, T., Avouac, J., Lyon-Caen, H., Bollinger, L., Galetzka, J., Genrich, J., Thomas, M., Chanard, K., Sapkota, S.N., Liu-Zeng, J. (2012). Convergence rate across the Nepal Himalaya and interseismic coupling on the main Himalayan thrust: implications for seismic hazard. *J Geophys Res*. 117: B04403

Aggarwal, S., Rai, S., Thakur, P., & Emmer, A. (2017). Inventory and recently increasing GLOF susceptibility of glacial lakes in Sikkim, Eastern Himalaya. *Geomorphology*, *295*, 39–54. https://doi.org/10.1016/j.geomorph.2017.06.014

Agrawal, N., Gupta, L., Dixit, J., & Dash, S.K. (2023). Seismic risk assessment for the North Eastern Region of India by integrating seismic hazard and social vulnerability. *Sustainable and Resilient Infrastructure 8*, sup1, 102-132

Aier, I., Singh, M.P., Thong, G.T., & Ibotombi, S. (2012). Instability analyses of Merhulietsa slide, Kohima, Nagaland. *Nat. Hazards 60*, 1347–1363. https://doi.org/10.1007/s11069-011-9913-6

Andreadis, K. M., Wing, O. E. J., Colven, E., Gleason, C. J., Bates, P. D., & Brown, C. M. (2022). Urbanizing the floodplain: global changes of imperviousness in flood-prone areas. *Environmental Research Letters*, 17(10), 104024. https://doi.org/10.1088/1748-9326/ac9197

Alimonti, G., & Mariani, L. (2023). Is the number of global natural disasters increasing? *Environmental Hazards*,1–17. https://doi.org/10.1080/17477891.2023.2239807

Anand, G., Rahangdale, A., Mantri, S.S.**,** Singh, S., & Kolathayar, S. (2022). Deterministic seismic hazard and landslide hazard zonation of Arunachal Pradesh. *J. Earth Syst. Sci. 131* **(**187) https://doi.org/10.1007/s12040-022-01942-w

Anbalagan, R., Kumar, R., Lakshmanan, K., Parida, S., & Neethu, S. (2015). Landslide hazard zonation mapping using frequency ratio and fuzzy logic approach, a case study of Lachung Valley, Sikkim. *Geoenviron Disasters* 2(6), 1–17, https://doi.org/10.1186/s40677-014-0009-y

Anbarasu, K., Sengupta, A., Gupta, S., Sharma, S.P., 2010. Mechanism of activation of the Lanta Khola landslide in Sikkim Himalayas. *Landslides 7*, 135–147, https://doi.org/10.1007/s10346-009-0193-0

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K., &Weesies, G. A. (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agric Ecosyst Environ 97*(1–3):295–308

Balamurugan, G., Ramesh, V., & Touthang, M. (2016). Landslide susceptibility zonation mapping using frequency ratio and fuzzy gamma operator models in part of NH-39, Manipur, India. *Natural Hazards*, 84 (1), 465–488

Barman, B.K., & Rao, K.S. (2019). Landslide hazard susceptibility mapping of upper Tuirial watershed, Mizoram using Remote Sensing and GIS techniques. *International Journal of Research and Analytical Reviews* 6 (1), 1624–1630

Barman, D., Baruah, A., M, A. B., & Aggarwal, S. P. (2023). Hydrological-hydrodynamic nexus for predicting flood plain inundation: a case study in Pagladiya-Putimari catchment, India. *Arabian Journal of Geosciences,* 16(9), 526. https://doi.org/10.1007/s12517-023-11620-w

Bathurst, J. C., Iroumé, A., Cisneros, F., Fallas, J., Iturraspe, R., Novillo, M. G., Urciuolo, A., Bièvre, B. de, Borges, V. G., Coello, C., Cisneros, P., Gayoso, J., Miranda, M., & Ramírez, M. (2011). Forest impact on floods due to extreme rainfall and snowmelt in four Latin American environments 1: Field data analysis. *Journal of Hydrology*, 400(3–4), 281–291. https://doi.org/10.1016/j.jhydrol.2010.11.044

Belho, K., Rawat, M.S. & Kumar Rawat, P. (2024). Geospatial Analysis of Seismotectonics for Microearthquake Hazard Zonation in Kohima District, Northeastern Himalayan Region of India. *Indian Geotech J*. https://doi.org/10.1007/s40098-023-00852-y

Belho, K., Rawat, M.S., & Rawat, P.K. (2023). GIS modelling to investigate environmental change and degradation in Kohima district of Nagaland, North East Hill region of India. *Environmental Monitoring and Assessme*nt.

Bentivoglio, R., Isufi, E., Jonkman, S.N., &Taormina, R. (2022). Deep learning methods for flood mapping: a review of existing applications and future research directions. *Hydrol. Earth Syst. Sci*. 26, 4345–4378. http://dx.doi.org/10.5194/hess-26-4345-2022

Bhandari, L.L., & Choudhary, L.R. (1975). Stratigraphic Analysis of Kadi and Kalol Formations, Cambay Basin, India. *Amer. Assoc. Petrol. Geol. Bull.*, v.59, pp.856-871

Bhattacharjee, K., & Behera, B. (2017). Forest cover change and flood hazards in India. *Land Use Policy*, 67, 436–448. https://doi.org/10.1016/j.landusepol.2017.06.013

Brivio, P., Colombo, R., Maggi, M., & Tomasoni, R. (2002). Integration of remote sensing data and GIS for accurate mapping of flooded areas. *Int. J. Remote Sens*. 23 (3), 429–441

Byers, A. C., Rounce, D. R., Shugar, D. H., Lala, J. M., Byers, E. A., & Regmi, D. (2019). A rockfall-induced glacial lake outburst flood, Upper Barun Valley, Nepal. *Landslides*, 16(3), 533–549. https://doi.org/10.1007/s10346-018-1079-9

CSIR-North Eastern Institute of Sceince and Technology, Jorhat, India

Cabrales, M.G.R. (2019). Exploitation of Resources. *In The Palgrave Encyclopedia of Global Security Studies,*1–3. Springer International Publishing. https://doi.org/10.1007/978-3-319-74336-3_332-1

Chan, D., &Wu, Q. (2015). Significant anthropogenic-induced changes of climate classes since 1950. *Scientific Reports*, 5(1), 13487. https://doi.org/10.1038/srep13487

Chen, Y., Khan, S., & Paydar, Z. (2010). To retire or expand a fuzzy GIS-based spatial multi-criteria evaluation framework for irrigated agriculture. *Irrig. Drain 59* (2), 174–188, https://doi.org/10.1002/ird.470

Chopra, B.R. (1977). Landslides and other mass movements along roads in Sikkim and North Bengal. *Bull. Int. As. Eng. Geol.* 16 (1), 162–166

Choudhury, M.K., & Nayak, T. (2003). Estimation of soil erosion in Sagar Lake catchment of Central India. *In: Proceedings of the inter- national conference on water and environment*, Dec15–18, 2003 Bhopal, India, pp 387–392

Cruz, R.A.D. (1992). The determination of suitable upland agricultural areas using GIS technology. *Asian Pacific Remote Sen J*. 5:123–132

Dai, F., & Lee, C. (2002). Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology* 42 (3–4), 213–228, https://doi.org/10.1016/s0169-555x(01)00087-3

Das R, Sharma ML, Wason HR, Gonzalez G, Chodhury D. (2019) A seismic moment magnitude scale. *Bull Seismol Soc Am*. 109(4):1542–1555.

Das, D. (2016). Changing climate and its impacts on Assam, Northeast India. Bandung: *Journal of the Global South*, 2(1), 1–13. https://doi.org/10.1186/s40728-015-0028-4

Das, I., & Deka, S. (2021). Impact of Flood on the Socio-Economic Conditions in the Southern Part of Kamrup District, Assam. *Space and Culture, India*, 8(4), 106–119.https://doi.org/10.20896/saci.v8i4.665

Das, R., Menesis, C., & Urrutia, D. (2023) Regression relationships for conversion of body wave and surface wave magnitudes toward Das magnitude scale, M_{wg}. *Nat Hazards 117*, 365–380. https://doi.org/10.1007/s11069-023-05863-9

Demirci, A., & Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcek- mece Lake watershed, northwest Turkey. *Environ Earth Sci* 66(3):903–913

Deshpande, R.S. (2022). Disaster management in India: are we fully equipped? *Journal of Social and Economic Development*, 24(S1), 242–281. https://doi.org/10.1007/s40847-022-00225-w

El-Swaify, S.A. (1997). Factors affecting soil erosion hazards and con- servation needs for tropical steep lands. *Soil Technol* 11(1):3–16

Feizizadeh, B., & Blaschke, T. (2013). GIS-multicriteria decision analysis for landslide susceptibility mapping: comparing three methods for the Urmia Lake basin, Iran. *Nat Hazards* 65 (3), 2105–2128, https://doi. org/10.1007/s11069-012-0463-3

Ganasri, B.P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. *Geosci Front* 7(6):953–961. doi:10.1016/j.gsf.2015.10.007

Gelagy, H.S., & Minale, A.S. (2016). Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed, north-western Ethiopia. *Int Soil Water Conserv Res* 4(2):126–136

Ghosh, C. (2013). Landslides induced damages due to recent Sikkim earthquake: strategies for geotechnical intervention. *In Proceedings of the international symposium on engineering under uncertainty: safety assessment and management (ISEUSAM-2012). Springer India* 1289–1298

Gupta, H. K. (2018). Review: Reservoir triggered seismicity (RTS) at Koyna, India, over the past 50 yrs. *Bull. Seismol. Soc. Amer*. 108 2907–2918

Gupta, H. K. (2021). Understanding anthropogenic earthquakes. *Curr. Sci.* 120(9) 1415–1416

Gupta, H.K. (2023). Himalayan Seismic Belt, Seismic Gaps and Related Issues. *J Geol Soc India* 99, 1187–1190 https://doi.org/10.1007/s12594-023-2450-6

Gupta, L., Agrawal, N., Dixit, J., & Dutta, S. (2022). A GIS-based assessment of active tectonics from morphometric parameters and geomorphic indices of Assam Region, India. *Journal of Asian Earth Sciences X* 8, 100-115, https://doi.org/10.1016/J.JAESX.2022.100115

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1992). Analysis of landslide sites: Kilbury Road, Kumaun Himalaya, India. *Current Science* 62 (7), 518-522

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1993). Environmental influences on landslide activity: Almora Bypass, Kumaun Lesser Himalaya. *Natural Hazards* 8, 153-170

Haigh, M. J., Rawat J.S., Rawat, M.S., Bartariya, S.K. & Rai, S.P. (1995). Interaction between forest and landslide activity along new highways in Kumaun Himalaya. *Forest ecology and management*, 78 (173-189)

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1997). Environmental influences on landslide activity, Almora Bypass, Kumaon Lesser Himalaya. *In Contemporary Approaches to Indian Geography (ed. Rais Akhtar)*. APH Publishing Corporation, New Delhi, 243-262

Holtrop, J.F., & Keizer, J. (1970). Some Aspects of the Stratigraphy and Correlation of the Surma Basin Wells, East Pakistan. *ECAFE Mineral Resources Development Series*, 36, 143–154.ICIMOD.2015

Jibhakate, M., Timbadiya, S.V.P., & Patel, L.P. (2023). Multiparameter flood hazard, socioeconomic vulnerability and flood risk assessment for densely populated coastal city. *Journal of Environmental Management*, 344, 118405. https://doi.org/10.1016/j.jenvman.2023.118405

Kayal, J.R., Baruah, S., Hazarika, D., & Das, A. (2022). Recent large and strong earthquakes in the eastern Himalayas: An appraisal on seismotectonic model. *Geological Journal* 57 (12), 4929–4938, https://doi.org/10.1002/gj.4576

Kolat, C., Ulusay, R., & Suzen, M.L. (2012). Development of geotechnical microzonation model for Yenisehir (Bursa, Turkey) located at a seismically active region. *Eng. Geol.* 127, 36–53, https://doi.org/10.1016/j. enggeo.2011.12.014

Kouli, M., Soupios, P., & Vallianatos, F. (2009). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ Geol* 57(3):483–497

Kumar, D., Thakur, M., Dubey, C.S., & Shukla, D.P. (2017). Landslide susceptibility mapping & prediction using Support Vector Machine for Mandakini River Basin, Garhwal Himalaya, India. *Geomorphology* 295, 115–125, https://doi.org/10.1016/j.geomorph.2017.06.013

Lampert, A. (2019). Over-exploitation of natural resources is followed by inevitable declines in economic growth and discount rate. *Nature Communications*,10(1), 1419. https://doi.org/10.1038/s41467-019-09246-2

Magnan, A. K., Pörtner, H.-O., Duvat, V. K. E., Garschagen, M., Guinder, V. A., Zommers, Z., Hoegh-Guldberg, O., & Gattuso, J.-P. (2021). Estimating the global risk of anthropogenic climate change. *Nature Climate Change*, 11(10), 879–885. https://doi.org/10.1038/s41558-021-01156-w

Mathew, J., Jha, V.K., & Rawat, G.S. (2007). Application of binary logistic regression analysis and its validation for landslide susceptibility mapping in part of Garhwal Himalaya, India. *Int. J. Remote Sens.* 28 (10), 2257– 2275, https://doi.org/10.1080/01431160600928583

Miller, R.W., & Donahue, R.L. (1990). *Soils: an introduction to soils and plant growth, 6th edn. Prentice Hall, Englewood Cliffs*

Mohanty, M. P., Mudgil, S., & Karmakar, S. (2020). Flood management in India: A focussed review on the current status and future challenges. *International Journal of Disaster Risk Reduction*,49, 101660. https://doi.org/10.1016/j.ijdrr.2020.101660

Moore, I.D., & Burch, G.J. (1986). Physical basis of the length slope factor in the Universal Soil Loss Equation. *Soil Sci Soc Am* 50:1294–1298

Nakata T (1972) Geomorphic History and Crustal Movements of the Foot-hills of the Himalaya. *Tohoku University Science Reports, 7th Series, Japan* 22: 39–177.

Orimoloye, I. R., Belle, J. A., & Ololade, O.O. (2021). Exploring the emerging evolution trends of disaster risk reduction research: a global scenario. *International Journal of Environmental Science andTechnology*, 18(3), 673–690. https://doi.org/10.1007/s13762-020-02847-1

Pimentel, D,, Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science* 267(5201):1117–1123

Pachauri, A., & Pant, M. (1992). Landslide hazard mapping based on geological attributes. *Eng. Geol.* 32 (1–2), 81–100, https://doi.org/10.1016/0013-7952(92)90020-y

Pal, I., Nath, S.K., Shukla, K., Pal, D.K., Raj, A., Thingbaijam, K.K.S., & Bansal, B.K. (2008). Earthquake hazard zonation of Sikkim Himalaya using a GIS platform. *Nat Hazards* 45 (3), 333–377, https://doi.org/10.1007/s1106 9-007-9173-7

Pradeep, G.S., Krishnan, M.V.N., & Vijith, H. (2015). Identification of criti- cal soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. *Arab J Geosci* 8(6):3697–3711

Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. *Geosci Front* 3(2):209–215

Rama, Rao. M.S.V. (1962). Soil conservation in India. *Indian Council of Agricultural Research*, New Delhi. Retrieved from http://krishi-kosh.egranth.ac.in/handle/1/2049015

Ramasamy, S.M., Gunasekaran, S., Saravanavel, J., Melwyn, J.R., Rajaperumal, R., Kathiravan, R., Palanivel, K., & Muthukumar, M. (2021). Geomorphology and Landslide Proneness of Kerala, India A Geospatial study. *Landslides 18*, 1245–1258, https://doi.org/10.1007/s10346-020-01562-9

Ramli, M.F., Yusof, N., Yusoff, M.K., Juahir, H., & Shafri, H.Z.M. (2010). Lineament mapping and its application in landslide hazard assessment: a review. *Bull Eng Geol Environ* 69, 215–233, https://doi.org/10.1007/ s10064-009-0255-5

Rawat, J.S., & Rawat, M.S. (1994). The Nana Kosi Watershed, Central Himalaya, India. Part-II: Human Impacts on Stream Runoff. *Mountain Research and Development*, 14:3, 255-260

Rawat, M. S. (2003). Pattern of headwater erosion in Animal Park catchment, Kumaon Himalaya.. *Nagaland University Research Journal (NURJ*), Vol. 1, p. 37-40. 25

Rawat, M. S. (2004). Geospatial information technology for development planning in Nagaland. In: *Economic Development in Nagaland: Prospects and Constraints* (eds. A. Sema, et. al.), N.V. Press, Kohima, p. 340-356

Rawat, M. S. (2011). *Environmental Geomorphology and Watershed Management*. Concept Publishing Company, New Delhi (ISBN-13:978-81-8069-758-6)

Rawat, M. S. (2013). Sustainable development in Nagaland through integrated watershed management: A case study from Kiliki River Basin. *International Journal of Development Studies and Research*, Vol. 2, 60-80

Rawat, M. S., & Furkumzuk, C. (2013). Environmental management and sustainable development in the Kiliki watershed of Nagaland. *Indian Journal of Environmental Studies*, Vol. 01, (01), 26-42

Rawat, M. S., & Haigh, M. J. (1998) Rainy season runoff and sediment yields of forested and non-forested catchments in Kumaun Himalaya. In: *Proceedings of the 8th International Conference on Soil and Water Conservation: Challenges and Opportunities* (eds. L. S.

Bhushan, I. P. Abrol and M. S. Ramamohan Rao). Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, Vol. II, p. 1458-1465

Rawat, M. S., Rawat, J. S., & Haigh, M. J. (1995). Patterns of headwater sediment yield from Himalayan pine forest. *In: Hydrological Problems and Environmental Management in Highlands and Headwaters* (eds. Josef Krecek et al.), Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi, p. 364-393

Rawat, M. S., Haigh, M. J. Krecek, J., & Rawat, J. S. (1999). Dissolved load of a Central Himalayan Forest headwater in an experimental catchment, India. *In: Biogeochemistry of Rivers in Tropical South and South East Asia.* (eds. Ittekkot, et. al.), Mitt. Geog. Palaont. Inst. Univ. Hamburg/SCOPE Sonderband Heft 82, Germany, Marz, p. 185-195

Rawat, P. K. (2011). Impacts of climate change and hydrological hazards on monsoon crop pattern in Lesser Himalaya: a watershed-based study. *International Journal of Disaster Risks Science*, Vol. 3 (2): 98–112

Rawat, P. K. (2014). GIS Development to monitor climate change and its geohydrological consequences on Non-monsoon crop pattern in Lesser Himalaya. *Int. J. Computers and Geosciences* 70: 80-95

Rawat, P. K., Pant, B., Pant, K.K., & Pant, P. (2021). Geospatial analysis of alarmingly increasing human-wildlife conflicts in Jim Corbett National Park's Ramnagar buffer zone: Ecological and socioeconomic perspectives. *International Journal of Geoheritage and Parks*. 10, 337–350. DOI: 10.2139/ssrn.3938066

Rawat, P. K., & Pant, B. (2023). Geoenvironmental GIS development to investigate Landslides and Slope Instability along Frontal zone of Central Himalaya. *International Journal of Natural Hazard Research*, Vol.3 (2), 196–204

Rawat, P. K., & Pant, C. C. (2016). Environmental Geoinformatics: Theory to Practice for Disaster Management, Lambert Academic Publishing, Saarbrücken Germany: 1–219

Rawat, P. K., Pant, C. C., & Bisht, S. (2017). Geospatial analysis of climate change and emerging flood disaster risk in fast urbanizing Himalayan foothill landscape. *International Journal of Geomatics, Natural Hazard and Risks*, 8(2): 418–447

Rawat, P. K., Tiwari, P. C., & Pant, C. C. (2012). Geo-diversity and its hydrological response in relation to landslide susceptibility in Himalaya: A case study using GIS. *Int. J. of Georisk* 6(4): 229-251

Rawat, P. K., Tiwari, P. C., & Pant, C. C. (2012a). Geo-hydrological database modeling for integrated multiple hazard and risks assessment in Lesser Himalaya: a GIS based case study. *Int. J. Nat. Hazards* 62(3): 1233–1260

Renard, K.G., & Foster, G.R. (1983). Soil Conservation—Principles of ero- sion by water. *In: Dregne HE, Willis WO (eds) Dryland Agriculture. American Society of Agronomy, Soil Science Society of America, Madison, WI, USA*, pp 155–176

Rentschler, J., Avner, P., Marconcini, M., Su, R., Strano, E., Vousdoukas, M., & Hallegatte, S. (2023). Global evidence of rapid urban growth in flood zones since 1985. *Nature*, 622(7981), 87–92. https://doi.org/10.1038/s41586-023-06468-9

Rudra, K. (2014). Changing river courses in the western part of the Ganga–Brahmaputra delta. *Geomorphology*, 227, 87–100. https://doi.org/10.1016/j.geomorph.2014.05.013

Saaty, T.L. (1980). The analytic hierarchy process. McGraw-Hill, New York

Sapkota, S.N., Bollinger, L.K., Linger, Y., Tapponier, P., Gaudemer, Y., Tiwari, D. (2013). Primary surface ruptures of the great Himalayan earthquakes in 1934 and 1255. *Nature Geosci*. 6(2)152:7176

Sattar, A., Goswami, A., Kulkarni, Anil. V., Emmer, A., Haritashya, U. K., Allen, S., Frey, H., & Huggel, C. (2021). Future Glacial Lake Outburst Flood (GLOF) hazard of the South Lhonak Lake, Sikkim Himalaya. *Geomorphology*, 388, 107783. https://doi.org/10.1016/j.geomorph.2021.107783

Shahiri, P. A., Noori, M., Heydari, M., &Rashidi, M. (2016). Floodplain Zoning Simulation by Using HEC-RAS and CCHE2D Models in the Sungai Maka River. *Air, Soil and Water Research*, 9, ASWR.S36089. https://doi.org/10.4137/ASWR.S36089

Srivastava, P., Singh, I.B., Sharma, M., & Singhvi, A.K. (2003). Luminescence chronometry and Late Quaternary geomorphic history of the Ganga Plain, India. *Palaeogeogr Palaeoclimat Palaeoeco* 197: 15–41

Srivastav, S.K., & Pandey, N. (2011). Search for provenance of Oligocene Barail Sandstones in and around Jotsoma, Kohima, Nagaland. *Journal of Geological Society of India* 77, 433-442

Srivastava,V., Nakhro, R., & Pandey, N. (2013): Geometry of mesoscopic folds in the vicinity of Disang and Piphima thrust in Kohima district, Nagaland

Strahler, A.N. (1956). Quantitative slope analysis. *Bull. Geol. Soc. Am*., 67: 571-596

Stott, P. A., Gillett, N. P., Hegerl, G. C., Karoly, D. J., Stone, D. A., Zhang, X., & Zwiers, F. (2010). Detection and attribution of climate change: a regional perspective. *WIREs Climate Change*, 1(2), 192–211. https://doi.org/10.1002/wcc.34

Sundriyal, Y., Vipin, K., Neha, C., Sameek, K., Rahul, R., & Mohit, K. P. (2023). Brief communication: The northwest Himalaya towns slipping towards potential disaster. *Nat. Hazards Earth Syst. Sci.*, 23, 1425–1431

Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, 10(1), 13768. https://doi.org/10.1038/s41598-020-70816-2

Thakur, V.C. (2004). Active tectonics of Himalayan Frontal Thrust and seismic hazard to Ganga Plain. *Curr. Sci.* 86:1554–1558

Tiwari, P. (2008). Land use changes in Himalaya and their impacts on environment, society and economy: A study of the Lake Region in Kumaon Himalaya, India. *Advances in Atmospheric Sciences*, 25(6), 1029–1042. https://doi.org/10.1007/s00376-008-1029-x

Tollan, A. (2002). Land-use change and floods: what do we need most, research or management? *Water Science and Technology*, 45(8), 183–190. https://doi.org/10.2166/wst.2002.0176

Tripathi RP, Singh HP (1993) Soil erosion and conservation. New Age International Publishers, New Delhi, p 10

USDA (1981). Rainfall erosion losses from cropland east of the rocky mountain. Handbook no. 282. US Department of Agriculture, Washington, DC

Valdiya, K.S. (1976). Himalayan transverse faults and folds and their parallelism with subsurface structures of the northern Indian Plains. *Tectonophys* 32: 353–386

VanDer, Knijff J., Jones, R.R.J., & Montanarella, L. (1999). Soil erosion risk assessment in Italy. Office for Official Publications of the European Communities, Luxembourg, p 32, EUR 19022(EN)

Wang, Z., Lai, C., Chen, X., Yang, B., Zhao, S., &Bai, X. (2015). Flood hazard risk assessment model based on random forest. *Journal of Hydrology*,527, 1130–1141. https://doi.org/10.1016/j. jhydrol.2015.06.008

Wentworth, C. K. (1950). A Simplified method of determining the average slope of land surfaces. *Am. J. Science*., Series 5, 20

Wischmeier, W.H., & Smith, D.D. (1978). Predicting rainfall erosion losses. Agriculture Handbook No. 537. US Department of Agriculture, Washington, DC, pp 285–291

Youe-Qing, X., Xiao-Mei, S., Xiang-Bin, K., Jian, P., & Yun-Long, C. (2008). Adapting the RUSLE and GIS to model soil erosion risk in a mountain's karst watershed, Guizhou Province, China. *Environ Monit Assess* 141(1–3):275–286

CHAPTER - 4

Environmental Impacts of Geomorphic Hazards

Studying the physical features of the environment is one of the scientific components of geography (Deorr, 1990). Worldwide, environmental conditions are always evolving since the environment is an open system (Pirazizy, 1992). Natural pressures, primarily linked to geomorphological forces, are the origins of both endogenic and exogenic mountain formation and alteration processes. Slopes are getting steeper in the Kohima hills as a result of the ongoing orogeny process, precipitation, and drainage. As a result of human occupation and activity, this steepness has become even more dangerous. Natural disasters are more likely to occur here due to the high relief energy and steep slopes. Particularly dangerous in this environment are issues with gravity, such as landslides, runoff, and erosion. One major problem with modern development strategies in these fragile ecosystems is the prevalence of utilizing lowland technologies in very unsuitable environments. Measuring the exact proportion of total pressure that may be attributed to natural processes, as opposed to human activity, is difficult, if not impossible (Cool, 1983). This means that there is more at play than just cause and effect when considering the impact of stresses on the ecology of the highlands. These systems are complex, dynamic, interacting, internally coherent, and affected by many other systems, both natural and man-made. According to Pirazizy (1989), these systems are in a perpetual state of self-adaptation. As mentioned in Chapter 3, the four most common geomorphic hazards in Kohima are landslides, soil erosion, flash floods, and earthquakes. These hazards have far-reaching consequences for both the environment and the population, especially as Kohima continues to urbanize and grow.

The term "environmental degradation" is used to describe the unwelcome and detrimental changes that take place in any kind of environment. This includes the geo-environment, which includes features like topography, geology, geomorphology, and seismotectonics, as well as the ecological and climatic environments, which include features like air, land, water, flora, fauna, and habitats (Rosenzweig and Parry, 1994; Howden et al., 2007; Schmidhuber and Tubiello, 2007; Rawat, 2014; Rawat et al., 2017). Since Earth's formation, there has been a problem with environmental degradation. Various geophysical, meteorological, chemical, and biological processes have been at work on Earth's environment ever since its formation about 4.5 billion years ago (Nakata, 1972; Valdiya, 1976; Thakur, 2004). In recent times, human activities have emerged as major causes of environmental degradation. (Turner et al., 1990; Parry et al., 1999; Porter and Semenov, 2005; Mearns, Rosenzweig, and Goldberg, 1997), among these activities are changes in land use, fast urbanization, deforestation, loss of biodiversity, acidification, pollution, and desertification. A number of recent studies have argued that human-induced environmental degradation is causing long-term problems like rising temperatures, extreme weather, and the worsening of natural geo-hydrological hazards like floods, forest fires, erosion, landslides, and droughts (Slingo et al., 2005; Lobell and Burke, 2010; Rawat and Pant, 2016; Fischer et al., 1996; 2005).

Environmental degradation in the Himalayan region is more severe and concerning than in other mountainous regions across the globe. Environmental degradation in the Himalayan region has been the subject of periodic examination by a number of studies dating back decades. Rosenzweig and Parry (1994), Fischer et al. (1996), Adams et al. (1995), Darwin and Kennedy (2000), Schlenker, Hanemann, and Fisher (2006), and Rawat (2017) all agree that these are ecological challenges, which include deforestation, degradation of land use, loss of biodiversity, habitat loss, and pollution. Earthquakes, landslides, slope failures, and subsidence are all examples of natural disasters that degrade geodiversity; active tectonics is one example (Valdiya and Bartarya, 1989; Tao et al., 2006; Sing, 2006; Rawat et al., 2012; 2012a; 2012b; Rawat, 2014; Rawat et al., 2017). Furthermore, these phenomena can be categorized as meteorological concerns, encompassing climate change-related extreme weather events, rising average temperatures, increasing evaporation loss, and altered patterns of precipitation (Hamilton, 1987; Easterling et al., 1993; Darwin, 1999; Rawat et al., 2007; 2007a; 2022; 2023). The rapid melting of glaciers, the drying up of watershed headwaters, the reduction in river water flow, and the change from perennial to seasonal rivers are all issues related to hydrology. (Baker and Jones, 2000; Challinor et al., 2005; Hansen and Jones, 2000; Iglesias et al., 2000, 2007). A number of recent studies in the central and eastern Himalayan region have shown that environmental degradation is speeding up climate change. These studies include those by Mearns et al. (1997), Katz and Brown (1992), Jain et al. (1994), Yang and colleagues (2023), and Zsagub and Ozdes (2022). Some examples of this include hotter weather overall, more frequent and intense storms, and higher rates of evaporation. Annual rainfall has decreased, monsoon rainfall has increased, cloud bursts have become more often, and floods have become more common as a result of these changes.

Most studies on environmental degradation in the Kohima have only looked at one or two goals, according to an examination of the available research. The interconnectedness of all environmental elements and sub-parameters must be acknowledged, though. These aspects include the geo-environment, which includes seismotectonics, geology, geomorphology, topography, and slope gradient, and which has been extensively discussed in Chapter 3. The ecological environment, which includes air, land, water, flora, fauna, and habitats, and the climatic environment, which includes temperature, rainfall, evaporation, and humidity, are also included in this consideration.

4.1. Land use-Landcover Change in Kohima District

4.1.1 Methodology

Geodiversity informatics: Geographical Variety Variability in geo-parameters, including earthquakes, active tectonics, geology, geomorphology, drainage pattern, slope, relief, and so on, is a key component of GIS modules. Through GIS mapping, a mix of supervised (based on substantial fieldwork) and unsupervised (based on laboratory work) picture interpretation techniques were used to study these geo-parameters. To complete this crucial task, we used Survey of India topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000 to georeference and co-register STRM and Google Earth satellite data acquired from their respective websites in a GIS context.

Land use informatics: The land use informatics module can detect changes in the spatial distribution of land use patterns on a decadal and annual basis. The analysis and mapping of land use for the relevant years were conducted using PAN merged data from 2002 and Indian Remote Sensing Satellite (IRS)-1C) LISS III (23.50 m spatial resolution) data. After then, the two datasets were combined for additional analysis. Before converting the false colour composite into intensity, hue, and saturation (IHS) colour space images, the LISS and PAN data were first co-registered with a root-mean-square (rms) error of 0.3 pixels. By utilizing the original high-resolution image as a substitute for the strength component and the hue and saturation components from the original RBG images, the reverse translation from IHS to RBG was executed. A land-cover/land-use map of the research region was created using this merged data product obtained by merging satellite data sets. Using computerized image processing methods backed by thorough ground truth assessments, objects in the satellite image were identified and interpreted. Afterwards, land-use from 2002 and 2023 were overlay to track the spatiotemporal change in the research area's land-use pattern. Time series based on the Normalized Difference Vegetation Index (NDVI) have been used to obtain extensive patterns of change across the region.

4.1.2. Degrading land use system: Figure 4.1 shows that the state capital city of Kohima and its surrounding sub divisional tows, as well as sub-urbanized villages, are experiencing a high pace of urbanization and land degradation, according to a geospatial study of land use pattern for the years 2002 and 2023.

Decreasing natural landscape and habitats (NL): The terrain is classified as a natural landscape, consisting of dense forest areas, open forest areas, dense shrub lands, and various water bodies such as lakes, ponds, rivers, and springs (see figure 4.1. The statistical analysis of the land use change exercise indicates that the natural landscape has reduced from 919.50 km^2 (93.93%) to 801.40 km^2 (81.86%) during the past two decades (2002-2023), with an annual rate of 5.91 km^2 (0.60%) (table 4.1). The yearly rate of decline in natural landscape varies from a maximum of 4.60 km^2 (0.47%) for open forest land area to a minimum of 0.06 km^2 (0.01%) for shrubs land area. For thick forest land area, the rate is 1.23 km^2 (0.13%), and for water bodies, it is 0.02 km^2 (0.01%) (figure 4.1 and table 4.1).

Increasing anthropogenic or human landscape (HL): The area that is used for agricultural techniques, including terrace and shifting cultivation, horticulture, and towns with road network, bridle paths, canals, and river dams, is classified as human landscape (figure 4.1). According to the statistical analysis of the land use change exercise, the area of natural landscape has expanded from 59.46 km^2 (6.07%) to 177.56 km^2 (18.14%) over the past two decades (2002-2023), with an annual growth rate of 5.91 km^2 (0.60%) (table 4.1). The annual decline in natural landscape varies between a maximum of 2.73 km^2 (0.28%) for build-up areas and a minimum of 0.49 km^2 (0.05%) for waste land. In the case of agricultural land, which includes Jhum or shifting farming, terraced farming, horticulture, and mixed farming, the decline is 2.69 km^2 (0.13%) and 0.02 km^2 (0.27%) respectively (figure 4.1 and table 4.1).

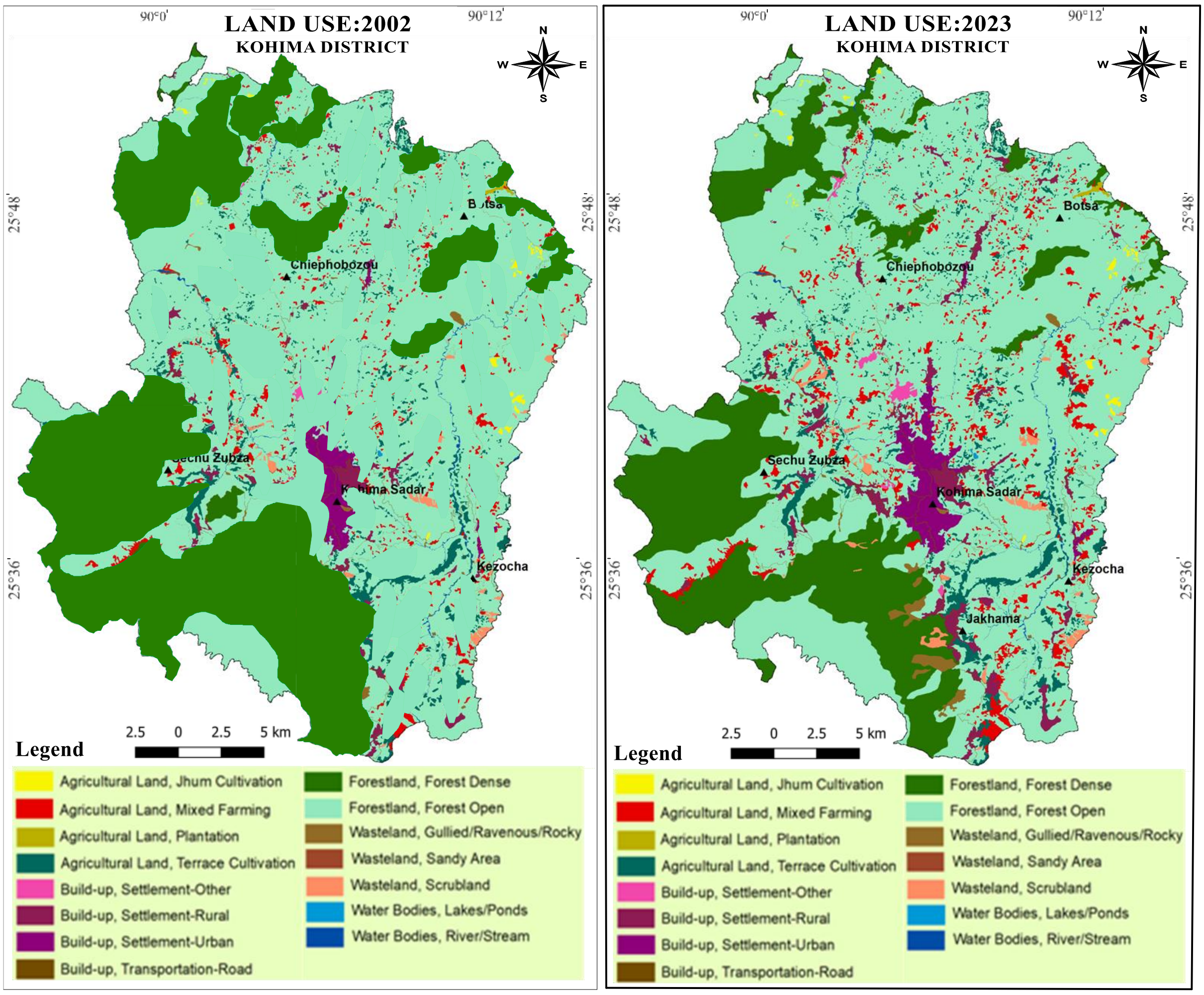


Figure 4.1: Spatial change in land use pattern in Kohima district, Nagaland during 2002 (left) to 2023 (right).

Table 4.1: Attribute data of land use change in Kohima district of northeast Himalaya region (2002-2023).

Land Use/ Land cover Classes		**2002**		**2023**		**Change 2002-2023**		**Annual trends of change**	
		km²	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
Natural landscape (NL)	Dense Forest	200.93	20.52	176.25	18.00	-24.68	-2.52	-1.23	-0.13
	Open Forest	705.49	72.07	613.47	62.67	-92.02	-9.4	-4.60	-0.47
	Water bodies	4.09	0.42	3.79	0.39	-0.3	-0.03	-0.02	0.01
	Shrubs land	8.99	0.92	7.89	0.81	-1.1	-0.11	-0.06	-0.01
	Total (NL)	*919.50*	*93.93*	*801.4*	*81.86*	*-118.1*	*-12.06*	*-5.91*	*-0.60*
Human Landscape (HL)	Build up area	30.76	3.14	85.32	8.72	54.56	5.58	2.73	0.28
	Waste Land	2.56	0.26	12.38	1.26	9.82	1.00	0.49	0.05
	Agricultural land	26.14	2.67	79.86	8.16	53.72	5.49	2.69	0.27
	Total (HL)	*59.46*	*6.07*	*177.56*	*18.14*	*118.1*	*12.06*	*5.91*	*0.60*
Total (NL+HL)		**978.96**	**100**	**978.96**	**100**	**-**	**-**	**-**	**-**

The table 4.2 provides a detailed representation of the different geomorphic hazards that occurred in the district over a 15-month period. Among these hazards, landslides had the highest frequency of occurrence. The impact of landslides was primarily on houses and paddy fields, with occasional severe effects on National Highway 29 and National Highway 2.

Table 4.2: Geomorphic calamities in Kohima from 15 May, 2017 to 29 August 2018 (Source: DDMA).

Event date	**Event type**	**Site**	**Impact on the environment and population**
15-05-2017	Landslide	NH-29	Road severely damaged
18-05-2017	Landslide	Peducha	Houses severely damaged
02-06-2017	Landslide	Nhachukou road	Road severely damaged, affected agriculture and paddy fields
21-06-2017	Landslide	Jotsoma	Paddy fields
25-06-2017	Landslide	Phesama	Road severely damaged
26-06-2017	Landslide	Kiruphema	Paddy fields
28-06-2017	Landslide	Kiruphema	Paddy fields
29-06-2017	Landslide	Kiruphema	Paddy fields
29-06-2017	Landslide	Peducha	Paddy fields and cracks and fissures developed which did not allow water to be retained in the terraces
31-06-2017	Landslide	Kiruphema	Paddy fields
08-07-2017	Landslide	Peducha	Paddy fields
08-07-2017	Landslide and change of river course	Mima	Paddy fields
11-07-2017	Land sinking	Peraciezie	Houses were severely damaged
14-07-2017	Landslide	Viswema	NH-2 severely damaged, 10-15 roads sunk, agriculture
14-07-2017	Landslide and Flash flood	Jakhama	Paddy fields
15-07-2017	Landslide	Kohima village	Paddy fields
15-07-2017	Landslide	Viswema	Paddy fields
17-07-2017	Landslide	Pezieliecie	Houses and crops
19-07-2017	Landslide	Viswema	Paddy
25-07-2017	Landslide	Viswema	Paddy
04-08-2017	Landslide and sinking	Tesophenyu	Fields
01-09-2017	Change of river course	Kezoma	Paddy fields
09-09-2017	Landslide	Themezhie	Houses affected
14-09-2017	Landslide	Kohima village	Paddy fields
06-10-2017	Landslide	Pezieliecie	Houses and crops
22-10-2017	Mudslide and Flash flood	Khuzama	Houses and crops
30-10-2017	Landslide	Meriema	Road damaged

05-04-2018	Landslide	T.Khel	Houses and retaining wall
11-04-2018	Landslide	Tinpati	Road
02-06-2018 to 11-06-2018	Landlside	Lower Tinpati	Link road completely cut off
15-06-2018	Landslide	Kiruphema	Houses
12-06-2018 to 19-06-2018	Landslide	Electrical colony	Houses affected
08-07-2018-29-08-2018	Landslide	Rusoma	Paddy fiels and houses
"	Landslide	Chiechama	Paddy fields, fisheries
"	Landslide	Seiya Phesa	Paddy fields
"	Landslide	Nerhe Model	Paddy fields and houses
"	Landslide	Nachama	Paddy fields
"	Landslide	Zeizou	Paddy fields
"	Landslide	Phekerkrie	Paddy fields
"	Landslide	Zhadima	Paddy fields, Fisheries and houses
"	Landslide	Tsiesema Basa	Paddy fields
"	Landslide	Tsiemekhuma	Paddy fields
"	Landslide	Tsiesema	Paddy fields
"	Landslide	Meriema	Paddy fields
"	Landslide	Nerhe Pheza	Paddy fields, houses and retaining walls
"	Landslide	Tsiemekhu Basa	Paddy fields
"	Landslide	Nerhema	Paddy fields and houses
"	Landslide	Seiyhama	Paddy fields
"	Landslide	Botsa	Paddy fields
"	Landslide	Chiephobozou town	Paddy fields and houses
"	Landslide	Nhachukou	Houses
"	Landslide	GMS Keyake	Houses
"	Landslide	Seikhazou	Houses
"	Landslide	Sanuoru	Houses
"	Landslide	NHAK	Houses
"	Landslide	L.Khel	Houses
"	Landslide	KSC Jotsoma	Houses
"	Landslide	Pokabozou	Houses
"	Landslide	D.Khel	Houses
"	Landslide	D.Block	Houses
"	Landslide	Officers Hill	Houses
"	Landslide	Kezieke	Houses
"	Landslide	Seikhazou	Houses
"	Landslide	KSC Jotsoma	Houses
"	Landslide	Paramedical	Houses
"	Landslide	Themezie	Houses
"	Landslide	Sepfuzou	Houses
"	Landslide	Old.M.Hill	Houses and retaining walls
"	Landslide	Pezielietsie	Houses, paddy fields, fisheries and retaining walls
"	Landslide	High School	Houses
"	Landslide	Themezie	Houses
"	Landslide	Sepfuzou	Houses
"	Landslide	Peraciezie	Houses

"	Landslide	AG	Houses
"	Landslide	Phezu	Houses
"	Landslide	Keziekie	Houses
"	Landslide	NH 29	Houses
"	Landslide	Daklane	Houses
"	Landslide	Perizie	Houses
"	Landslide	AG	Houses
"	Landslide	Chedema	Houses
"	Landslide	Peducha	Houses
"	Landslide	Phezu	Houses
"	Landslide	Mengujuma	Houses and paddy fields
"	Landslide	Zubza	Houses
"	Landslide	Khuzama	Houses and paddy fields
"	Landslide	Mima	Houses
"	Landslide	Phesama	Houses and paddy fields and fisheries
"	Landslide	Viswema	Houses
"	Landslide	Jakhama	Houses and paddy fields
"	Landslide	Pfuchama	Paddy fields
"	Landslide	Kezo town	Houses and paddy fields
"	Landslide	Kezoma	Paddy fields
"	Landslide	Kezo vasa	Paddy fields
"	Landslide	Kidima	Paddy fields
"	Landslide	Mitelephe	Paddy fields
"	Landslide	Kijumetouma	Paddy fields
"	Landslide	Dihoma	Paddy fields
"	Landslide	Sakhabama	Paddy fields

4.2. Road Constructions and Land Degradation:

Recent research on road-induced geomorphic hazards has demonstrated that road development has had a substantial influence on the occurrence of these hazards along hill roads. This has resulted in the disturbance of the landscape ecology and led to significant environmental deterioration of both physical and cultural landscapes. The aforementioned findings were recorded by Haigh in four separate publications (1979 a, 1979 b, 1984 a, and 1984 b), Valdiya in 1985, Haigh and colleagues in 1988, and Moseley in 1980. In the area near Nelson, New Zealand, Moseley (1980) found that road construction contributed an annual amount of 750-800 m^3 per km of debris to the sediment budget of the region. Haigh (1979 a) found that the construction of roads in Mussoorie, situated in the Central Himalayas, had led to a 5-10% increase in the movement of sediment. According to Valdiya (1985), the building of 44,000 km of roads in the Himalayas has led to the production of 2,650 x 10 -6 m^3 of debris. Furthermore, on an annual basis, each kilometer of these roads generates 550 cubic meters of debris as a result of landslides and rockfall. As a result, a significant amount of 24 million cubic meters of silt moves down the slopes each year, resulting in damage to flora, springs, and streams. The yearly rate indicated above exhibits clear swings. According to the Border route Organization (BRO), the annual sedimentation rate on the Jammu Srinagar Highway in Kashmir is expected to be as high as 724 cubic meters per kilometer. The annual precipitation rate on the Arunachal Pradesh Highway is 591 cubic meters, while on the Tanakpur-Tawaghat route in Kumaun Himalaya, it is 411 cubic meters (Haigh et.al., 1988). Haigh et.al. (1988) undertook an extensive investigation into the factors linked to heightened landslide activity on two hill roads situated in Almora and Nainital of the Kumaun Himalaya region. The investigation reveals that 32% of the road cut is affected by rockfall, whilst 27% is impaired by the slumping of rock or regolith.

Upon conducting on-site verification of the landslide zone map and comparing it with other socioeconomic maps, it became evident that landslides pose a significant problem in the research region. The presence of densely populated urban areas, including the state capital city Kohima, along with six sub-district headquarters (Botsa, Chiephobozou, Kezocha, Jakhama, Kohima sadar, Sechu Zubza), and numerous growing sub-towns located between multiple villages, in areas with a significant risk of landslides (as shown in Figure 4.2), is particularly concerning. Despite the ongoing and unregulated expansion of urban areas and the associated establishment of infrastructure, the adverse effects on the economy and society persist consistently each year. This toll includes the devastation of roadways, harm to communities, loss of human lives, and deterioration of the environment. Environmental degradation encompasses substantial deforestation, heightened erosion, extensive soil and rock displacement, and the accumulation of silt in downstream riverbeds. These variables exacerbate the risk of flooding during the rainy season. Previous studies have raised these concerns regarding the Himalayas (Pal et al., 2008; Balamuruga et al., 2016; Rawat et al., 2012; Dutta et al., 2021; Gupta et al., 2022; Nokendangba et al., 2021) and the broader Himalayan region (Kumar et al., 2017; Dobhal et al., 2013; Rawat et al., 2015; Kayal, 2022; Agrawal, 2023). Figure 4.2 illustrates the spatial distribution of landslides in various risk zones, indicating that the majority of landslides occur in areas classified as having high and very high levels of hazard. Furthermore, it reveals that in these regions, a significant number of landslides occur in urban areas that have been developed, agricultural lands, and next to highways, resulting in significant economic and social harm, such as the destruction of transportation networks, communities, commercial structures, agricultural lands, and the natural ecosystem.

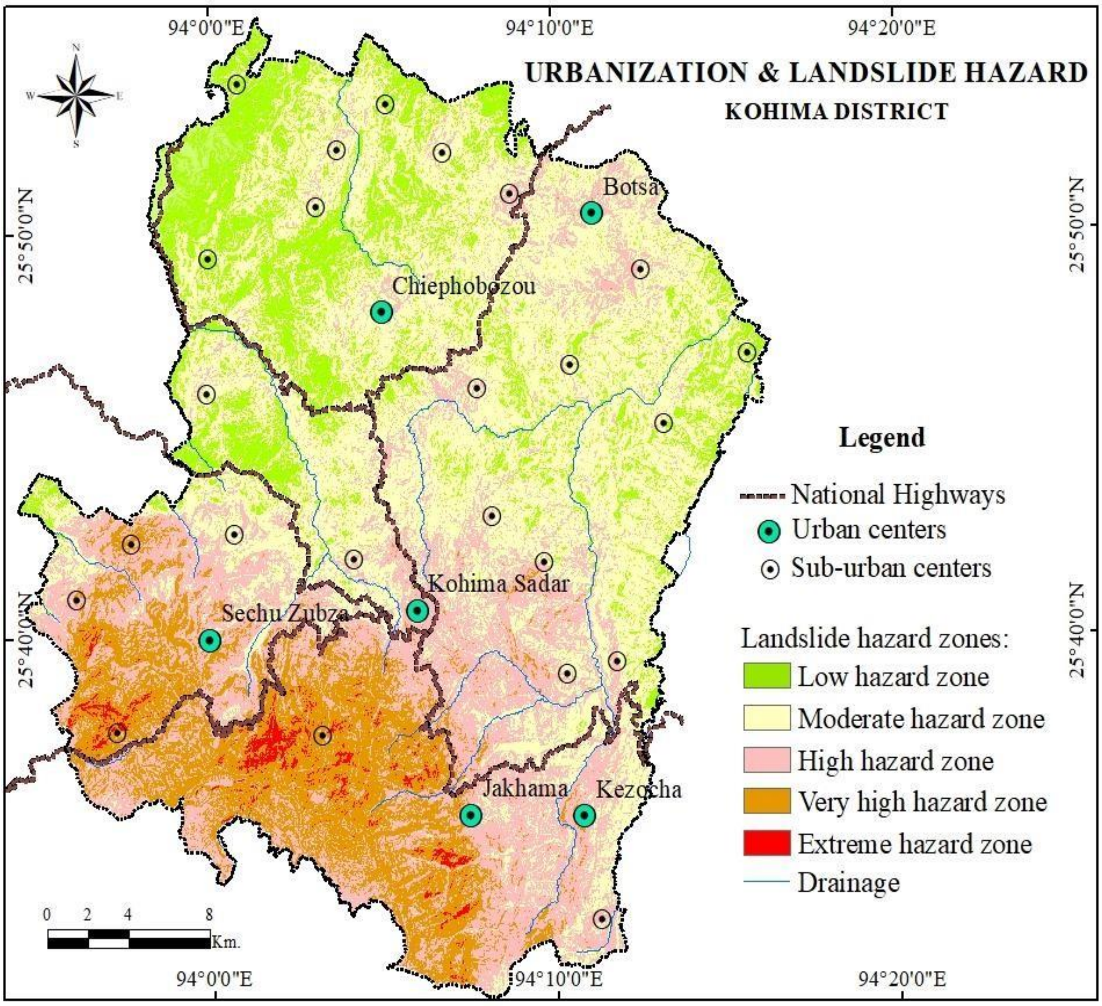


Figure 4.2: Urban and sub-urban centers in high landslide hazard zones of Kohima district, Nagaland.

During the fieldwork, a detailed survey was conducted on road-induced geomorphic hazards along the Kohima-Dimapur highway NH-29. The results have been presented in the following sections.

4.2.1. Road induced landslide on NH-29

The Old KMC Dumping landslide, often referred to as the Dzuchie landslide, is a well-known landslide along NH 29 that connects Dimapur and Kohima. This landslide remains active throughout the year due to ongoing subsidence, which is particularly exacerbated during the monsoon season because of constant rainfall.

In May 2019, a team of 5 individuals examined a 2-kilometer section of the road and gathered comprehensive data on the environmental and human factors that contribute to landslide threats caused by the road. The road segment is located between the latitude coordinates of 25º40’59.19” to 25º41’17.85” N and the longitude coordinates of 94º04’20.17” to 94º03’32.26” E. The location is situated 7km away from the TCP gate junction of Kohima town. It is divided into 6 sections, each of which experiences disturbances. These disturbances are caused by streams that intersect the national highway, indicating the presence of abundant underground water. This water plays a significant role in causing the instability of the area. The entire 2 km stretch has been utilized for depositing soil materials resulting from rock excavation for the purpose of road building.

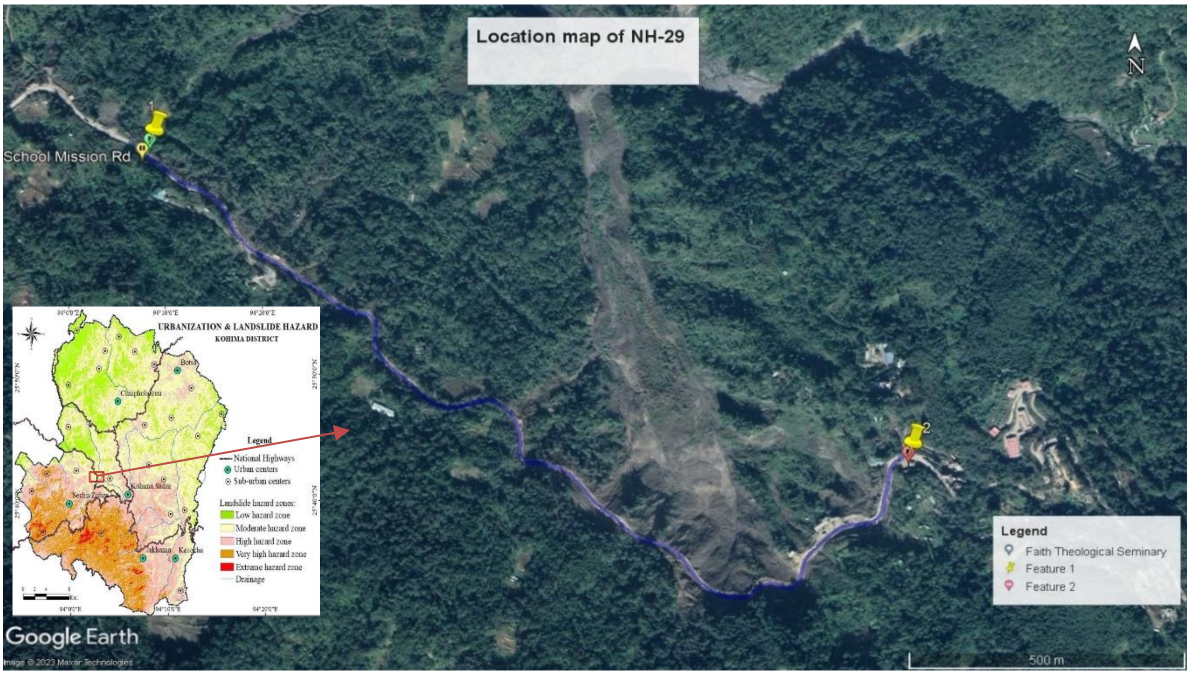


Figure 4.3: The 2km stretch of NH-29 indicated by point 1 to point 2 (Source: Google Earth)

The first section: The area, located at coordinates 25°40’59.19” N and 94°04’20.17” E, has a length ranging from 0 to 150 meters and an elevation of 1176 meters. It is primarily characterized by the presence of shale and sandstone rock formations. The width of the road in this area is around 3 meters. The vegetation was discovered to be scarce and deteriorated as a result of road building operations, particularly on lower slopes. The soil depth was measured to be 1 meter. The excessive deposition of earth materials downhill as a result of road excavation and landslides exacerbates the instability of the already precarious downhill region. It was discovered that the residences in that area were leaning, with power lines presenting a greater danger due to the slanted and unstable electric poles. The presence of intricate bending and faulting was seen in the debris flow, indicating a sophisticated geological process. Approximately 20% of the landslide was mitigated by the application of

Indigenous bamboo hammering, which involved the construction of a traditional check dam both upslope and downslope.

Plate 4.1: Tilted electric posts and houses and dumping of landslide materials in the selected section 1 of NH-29 selected 2km stretch Kohima

The second section: The length of the area spans from 150 to 950 meters and is located at coordinates 25°40'50.73" N and 94°04'10.40" E. It has an elevation of 1167 meters. The rocks consist of shale and sandstone and the road has a width ranging from 5 meters to 8 meters. A retaining wall was previously constructed downslope, but it was subsequently demolished when the landslide occurred. The landslide was classified as a debris slide. A significant occurrence of water logging was observed at a soil depth of 40 cm. The stream was situated at coordinates 25°40'53.87" N and 94°04'04.64" E, with an elevation of 1149m. A rock outcrop measuring approximately 1 square meter was discovered at coordinates 25°40'52.08" N and 94°04'07.33" E, at a height of 1154 meters. The rocks at this site exhibit a little inclination and are arranged in six layers, with a joint density of 10 joints per square meter.

Plate 4.2: The collapsed retaining wall in section 2 of NH-29 selected 2km stretch, Kohima

Plate 4.3: Rock exposure and landslide scars found in section 2 of NH-29

The third section: The length measures from 950 meters to 1.1 kilometers and is situated between the coordinates 25°40’58.83” N and 94°03’56.46” E, at a height of 1125 meters. At this location, the geological composition consists mostly of shale and sandstone, and the width of the road is around 7 meters. In this particular area, a stream was observed to have a water flow rate of 1 litre every 2 seconds. This occurred in April 2019. The landslide in this location was classified as a debris slide.

Plate 4.4: Stream found in section 3 with indication of joints and fracture on the rock surface of NH-29. During monsoon months, this stream become hazardous due to its flooding.

The fourth section: The length spans a distance of 1.1 km to 1.3 km and is situated at the coordinates 25°41’02.95” N and 94°03’53.20” E. It has an elevation of 1108m. The predominant rock type in this location was mostly sandstone. This segment had terrace fields and a banana tree canopy, with a 10-meter-wide road and a landslide characterized by debris.

Plate 4.5: The downslope and upslope of section 4 of NH-29, Kohima sliding down with tilted bamboo and trees.

The fifth section: The distance extends from 1.3 kilometers to 1.9 kilometers in the coordinates 25°41’06.62” N and 94°03’46.86” E, with an elevation of 1084 meters. The geological formations in this area consist predominantly of shale and sandstone. The road has an estimated width of 10 meters. The stone crusher is situated at a distance of 1.74 kilometers, with coordinates of 25°41'12.53" N and 94°03'38.04" E, with a height of 1077 meters. Subsidence occurs as a result of disruption caused by the movement of water across the soil.

The sixth section: The survey concludes at a distance ranging from 1.9 km to 2 km. The land conditions gradually improve with more vegetation and a flat terrain as it approaches the plain portions of Dimapur district. The rock formations present were mostly of granite and sandstone, and there were no discernible signs of landslides. The landform condition has improved with the addition of metal roadways, located 500 meters distant from the designated part.

Table 4.3: General stratigraphy of the stretch of the 2km road of NH-29

Age	**Group**	**Formation**	**Lithology**
Oligocene to Upper Cretaceous	Barail and Disang Transition Zone	Lower Barail Upper Disang	Shale-sandstone, Sandstone-Shale and sandy lamination

The whole 2km stretch of slide located here is a substantial debris flow that occurs in the Disang-Barail Transition zone. The slide consists predominantly and wholly of shale and sandstone lithology. The region is characterized by intricate folding and faulting, resulting in asymmetrical folds that generate varying permeability and shear strength within the same rock type. This promotes the infiltration of water, leading to the development of shallow perched aquifers and ultimately causing slope failure.The slope of the region where the landslide occurs varies from 15^o-25^o, which is conducive to significant landslides. This slope allows for prolonged water retention, resulting in saturation of the upper layer and an increase in the perched groundwater level. Because of the abundant groundwater in the area, it is improbable for the land to remain stable until all of it is extracted.

The convergence of its geomorphological, geological, and environmental factors is leading to hazardous occurrences of mass movement, landslides, and rock avalanches. In 2011, the monsoon season experienced an excessive precipitation of more than 1700mm, resulting in substantial landslides caused by the topographical characteristics of the region. In 2017, following a 6-year interval, another severe landslide occurred due to very heavy rainfall exceeding 2000mm in both 2017 and 2018. During the period from 2011 to 2021, these two years experienced the most substantial precipitation ever recorded, leading to considerable destruction and loss. Moreover, the slide continued to occur consistently throughout the year 2019 due to human activities, including the earthwork involved in road development. Constructing roads on steep terrains requires the removal of 60000m3 of garbage for every 1 km of road, which has a significant negative impact. Road areas undergo erosion at a rate that is tenfold higher than erosion caused by farmland, two hundredfold higher than erosion caused by grassland, and two thousandfold higher than erosion caused by forested land. Disposing of excavated trash from road construction exacerbates the strain on the soil. The recurrent and extensive landslides in this region during the monsoon period led to road blockages, resulting in substantial disruptions to commerce and transportation. This route functions as a vital connection between Assam and Manipur, serving as the main mode of transportation and communication for the entire state and surrounding areas. Disruption has been identified in both the designated research zone and its surrounding areas. While traveling south along the road in the district, we also encounter such calamities, leading to substantial agricultural damages, property destruction, and disruptions to transportation.

Plate 4.6: Dumping of road cut materials along the NH-29 highway due to road construction which is responsible for downstream deforestation, killing of vegetations and drying up of springs.

Plate 4.7: Indigenous treatment of landslide by bamboo hammering and other measures for checking of land degradation and soil erosion downslope of NH-29.

Most of the landslides that occurs in Kohima are road induced landslides and following are a list of reported landslides under PWD (NH) Nagaland.

Table 4.4: Details of Landslide prone areas or recurring slides under PWD (NH) Nagaland (DDMA)

Sl. No.	**NH No. Old/New**	**Chainage and Landmark**	**Name of the Division**	**Nature and description of Disaster**
1	61/2	Km 7.600 (Meriema Village)	Kohima	Landslide at this location occurred for the first time and was cleared on 3.7.2018
2	61/2	Km 7900 to Km 8.150 (Meriema Village)	Kohima	This particular stretch is a subsidence area and numerous landslides have occurred in the past completely damaging the retaining wall last year and blocking the whole highway. Retaining wall constructed in June 2018 under Flood Damage Repair Fund.
3	61/2	Km 8.800 (Meriema Village)	Kohima	Landslide at this location occurred for the first time and was cleared on 3.7.2018

4	61/2	Km 10.80 (Meriema Village)	Kohima	Unstable hill slope. Landslide was cleared once last year and the current slide was cleared during the first week of July.
5	61/2	Km 11.200 (Tsiesema Village)	Kohima	Occurred due to fresh cutting of approach road by private landowners and cleared on 10.7.2018.
6	61/2	Km 18.50 (Near Pheja Village)	Kohima	Subsidence of about 50m stretch caused due to instability of soil. Retaining wall constructed during 2014 but collapsed in August 2016. Landslide was cleared by deploying machinery. The road was filled with granular sub base(GSB) during Oct 2017.
7	61/2	Km 18.60 (Near Pheja Village)	Kohima	Landslide from hillside occurred twice in Aug 2017 and May 2018. Landslide cleared by deploying machinery and opened to traffic.
8	61/2	Km 19.60 (Pheja Village Road Junction)	Kohima	Subsidence of the stretch due to instability of the soil in nature. The pavement surface developed numerous cracks due to valley side sliding. Retaining wall was constructed in Oct 2015 but it collapsed. The road was filled with sub base in the affected area.
9	61/2	Km 20.60 (Between Pheja Village and Nerhiema Village)	Kohima	Massive landslide occurred from hill side due to erosion on July 2017 and May 2018. Landslide cleared by deploying machinery and opened to traffic.
10	61/2	Km 22.700 (100m away from the Nerhiema Village)	Kohima	Subsidence due to valley side slope unstability (stream and paddy filed cultivation). The road was filled with granular sub base in the affected area.
11	61/2	Km 25.600 (Ciephobozou Town, below BSNL)	Kohima	Subsidence of the stretch due to valley side sliding and unstability of the sub-soil. The road was filled with granular sub-base to achieve the original road level.
12	61/2	Km 31.300 (Below Nachama Village)	Kohima	Landslide from rocky hill side due to thermal variation as well as slope instability.

13	61/2	Km 33.300	Kohima	Subsidence of about 120 m due to instability of soil in nature. The pavement surface badly affected by eroding mudslides from hill side causing blockage of the road for continuous 2 days. In 2010 the department has tried to divert the road by surveying feasibility but couldn't find any alternate alignment. Gabian wall was constructed on both hill side and valley side to retain the erosion. Bench cutting of earth also done on the hillside to avoid further slides. The road was filled with granular sub-base to achieve the original road level.
14	61/2	Km 33.500	Kohima	Breaching of shoulder due to instability of slope in the valley side caused by scouring of drainage water. Retaining wall and drainage work was done on valley side during 2016-2017

Figure 4.4: Road destruction due to landslide between Dimapur and Kohima city.

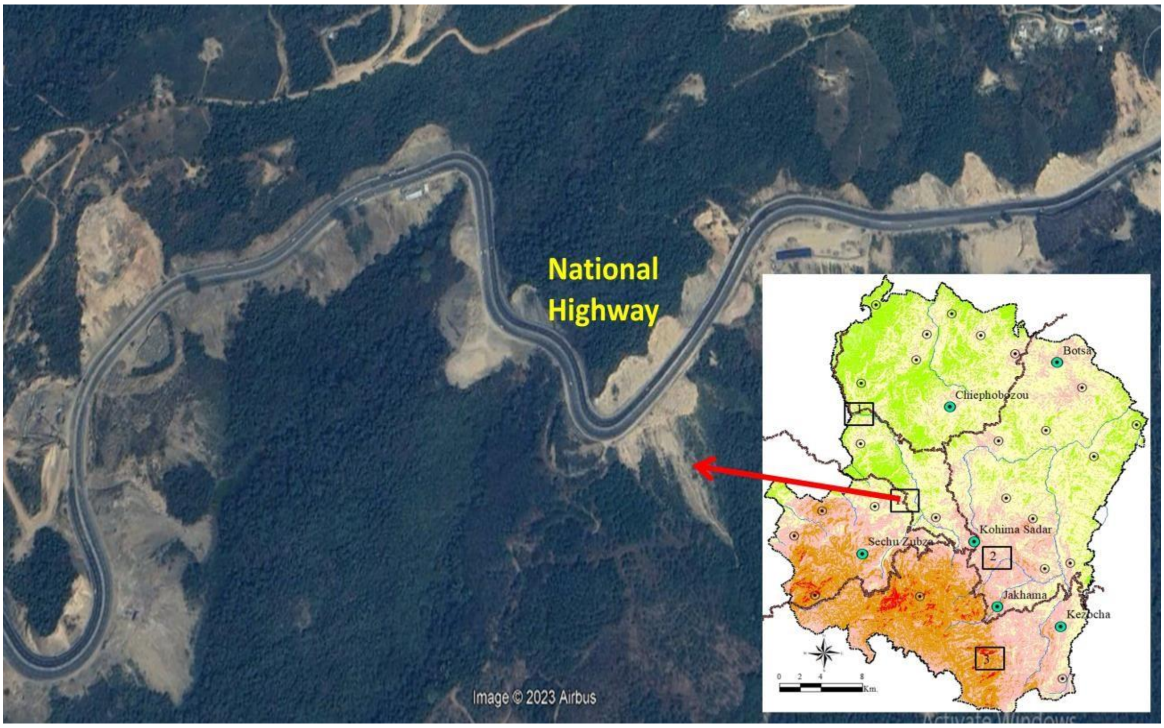


Figure 4.5: Road destruction due to landslide between Dimapur and Kohima city

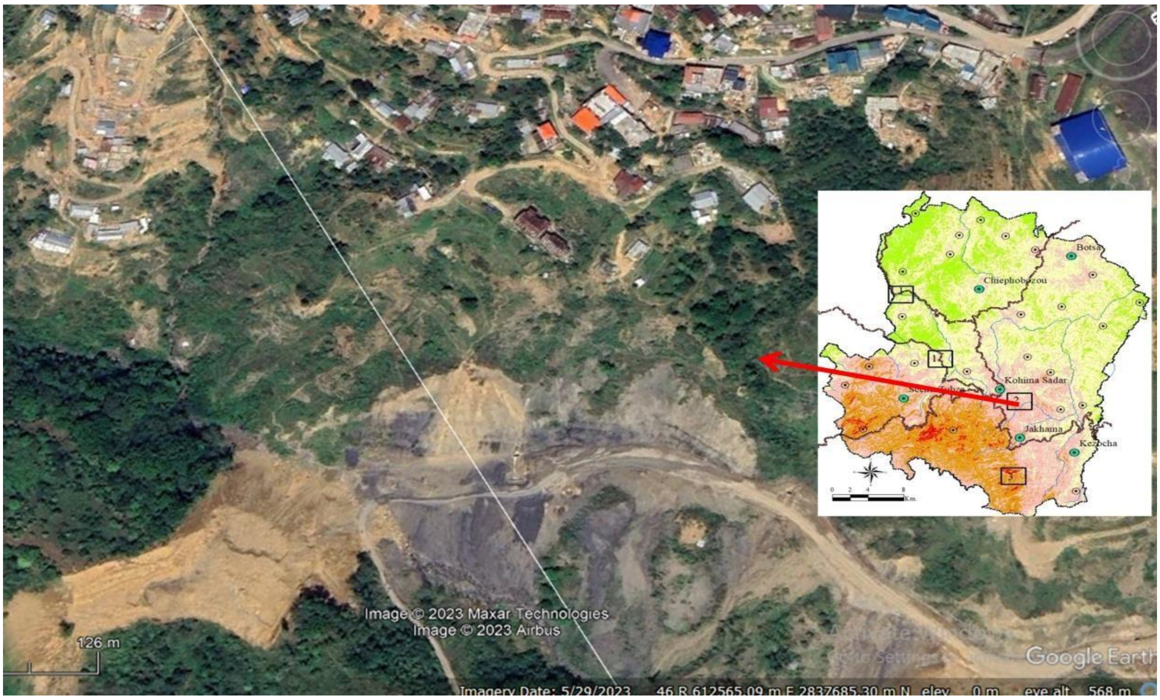


Figure 4.6: Slope failure in the southern slope of Kohima district, Nagaland

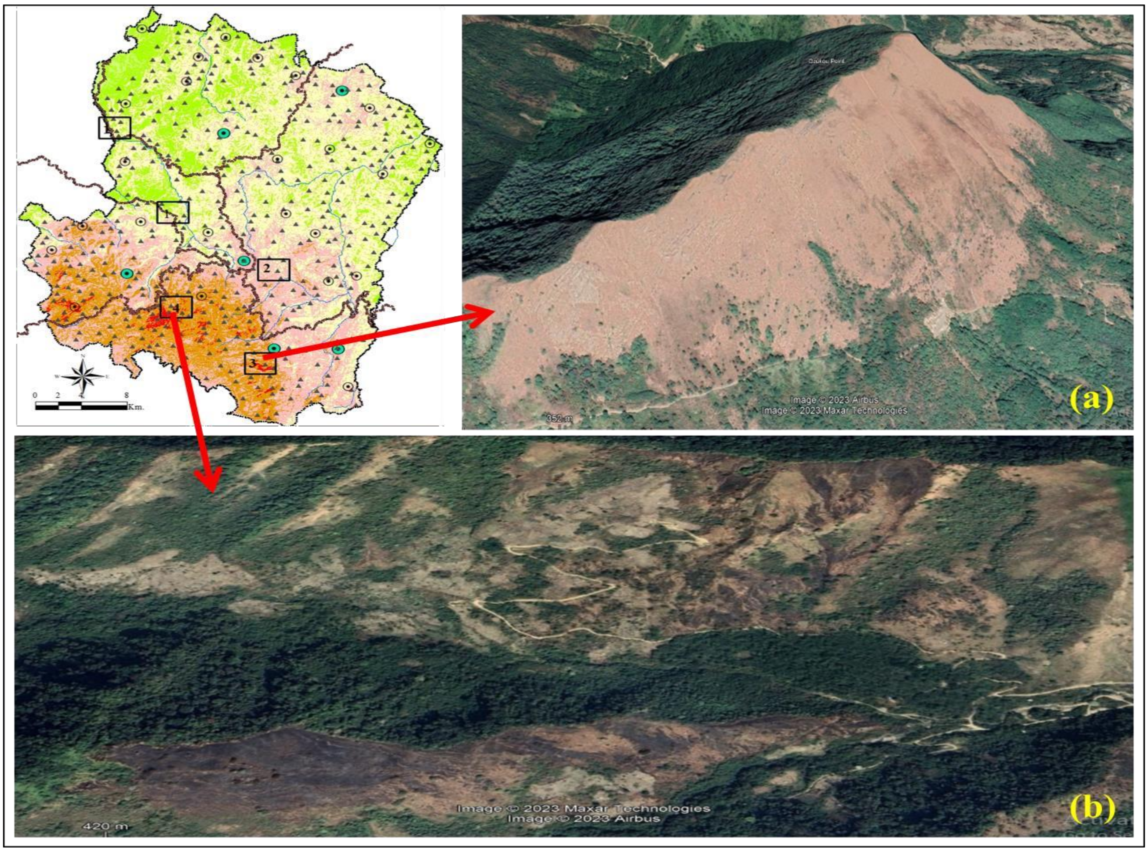


Figure 4.7: Deforestation (a) and crop land degradation (b) due to landslide in Kohima district

Soil erosion is another geomorphic hazard that is linked to landslides. The picture below illustrates the impact of soil erosion on the urbanized region of the research area. Human activities, such as fast-paced infrastructure development and extensive road cutting for construction purposes, are the primary drivers of erosion, which in turn leads to landslides. On the other hand, natural factors such as heavy rainfall, the presence of young and easily eroded rock formations, and the reshaping of the landscape contribute to the increased rate of soil erosion.

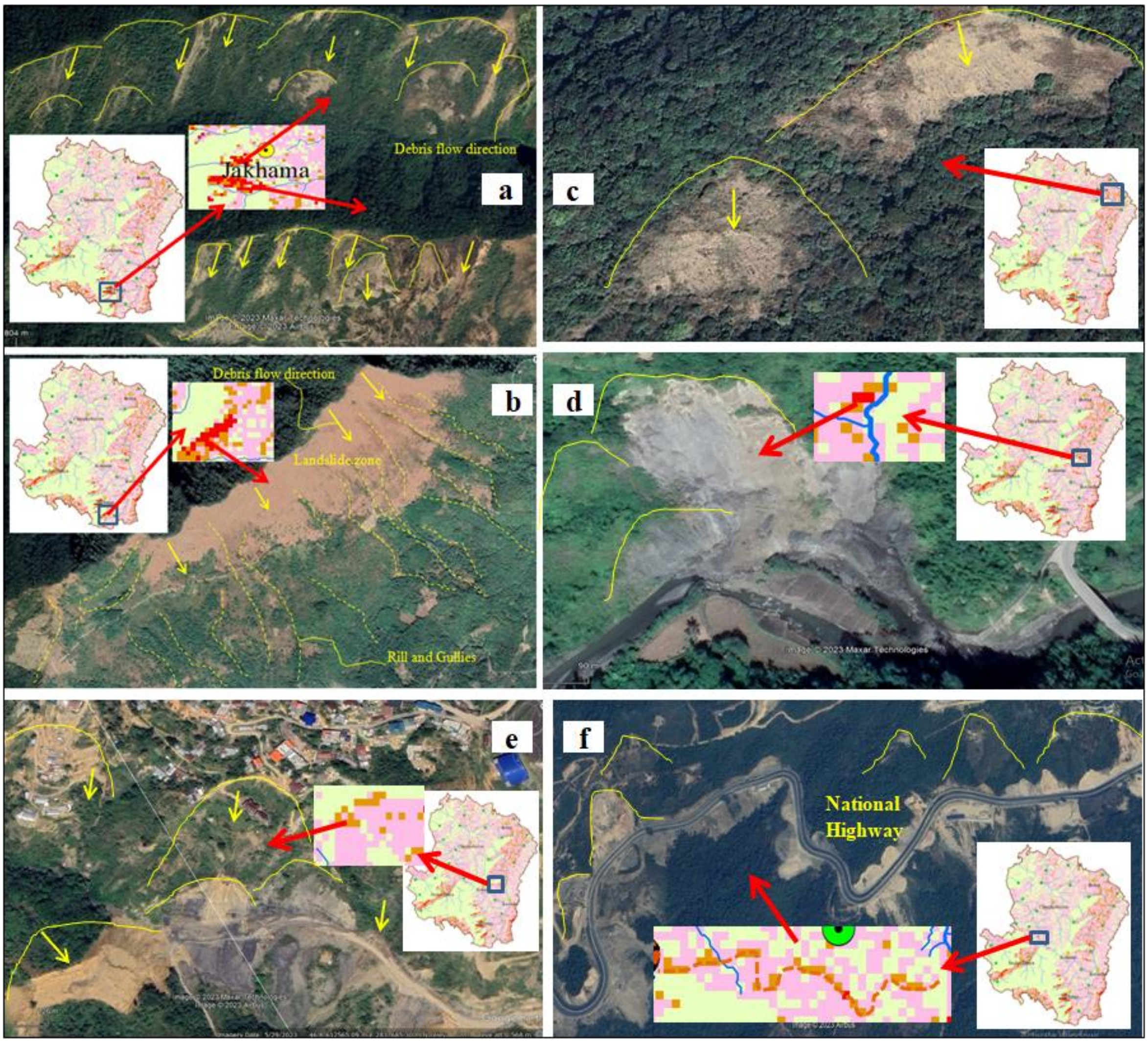


Figure 4.8: Erosion and associated geomorphic hazards along major roads of the study area which are responsible for environmental hazards in and around (a,b,c,d), settlements (e), and roads (f).

4.3. Flash Floods and Land Degradation

The flash flood hazard zone study is a cause for serious concern for the study area because the majority of the densely populated urban centers are located in the moderate to very high hazard zone. These urban centers include the state capital city of Kohima, six sub-district headquarter towns (Botsa, Chiephozou, Kezocha, Jakhama, Kohima sadar, and Sechu Zubza), and a growing number of sub-towns that are main crevice centers in between two or more villages (Figure 4.6). Despite the fact that rapid unplanned urban growth and associated infrastructure development are occurring year after year in the region, causing socioeconomic losses such as the destruction of roads, damage to settlements, human casualties, and environmental degradation through massive large-scale deforestation, accelerated erosion, mass movement, and sedimentation in river beds further downstream, these problems continue to occur. Such concerns have also been expressed by some pioneer studies from eastern Himalaya in particular (Pal et al. 2008, Balamuruga et al. 2016, Rawat et al. 2012, Dutta et al. 2021, Gupta et al. 2022, Nokendangba et al. 2021) and other part of the Himalaya in general (Kumar et al. 2017, Dobhal et al. 2013, Rawat et al. 2015, Kayal 2022, Agrwal 2023).

In regards to Nagaland state, which is located in the eastern Himalayas, the frequency and severity of floods are increasing, affecting both rural and urban areas. In urban areas, the increase in population and expansion of human settlements into flood-prone and hazardous areas such as erosion zones, debris flow areas, and landslide-prone areas are the main causes. In rural areas, the practice of shifting agriculture and the need for temporary infrastructure such as roads, paths, and water lines contribute to the problem (Rawat 2013, 2013a, 2014, 2017). The study region, namely the Kohima district of Nagaland, is also encountering this issue. Here are some Kohima district flood-affected places that are being displayed. Figure 4.9 illustrates the uncontrolled expansion of urban areas on unstable inclines and narrow valleys in Kohima city, which is extremely vulnerable to flooding and other hydrological dangers like as erosion, mass movement, and landslides. This practice is occurring in many locations around the district, namely in urban and suburban areas. The increase in sediment deposition from urban areas upstream has led to a rise in river beds downstream. This, in turn, causes erosion, landslides, and slope failure in foothill areas during the rainy season (figure 4.11). Additionally, there is flooding along the river lines in alluvial plain areas (figure 4.12).

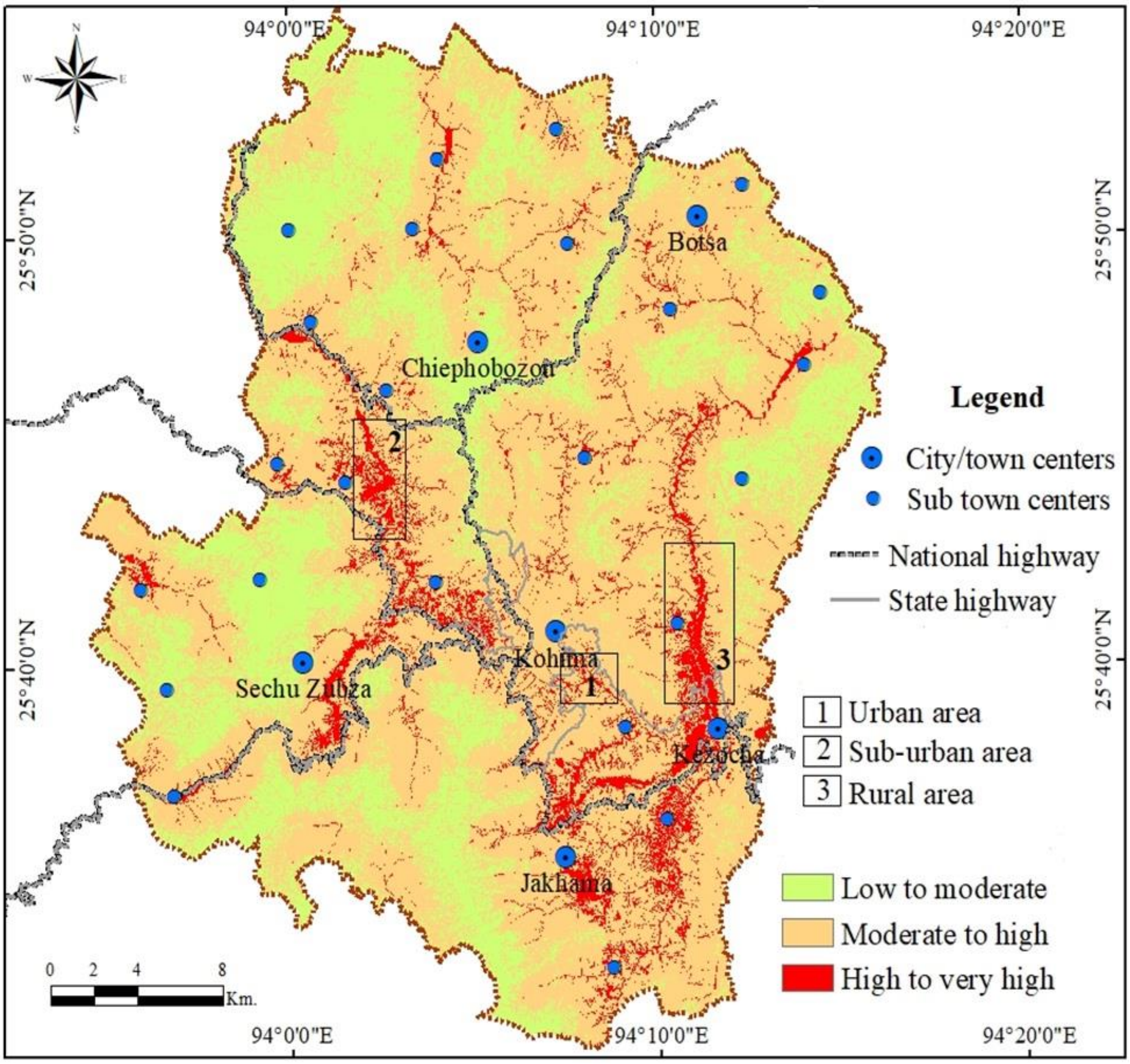


Figure 4.9: Urban and sub-urban centers in high Flash flood hazard zones, Kohima district, Nagaland.

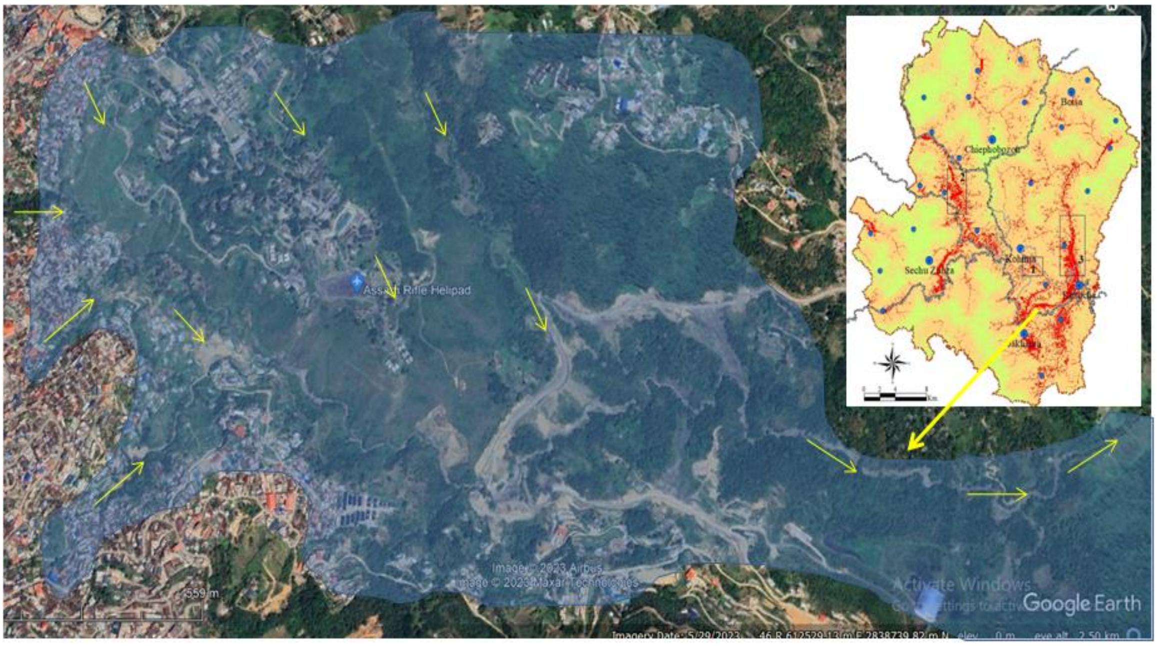


Figure 4.10: Unplanned urban growth in high runoff and flash flood hazard zone in Kohima city.

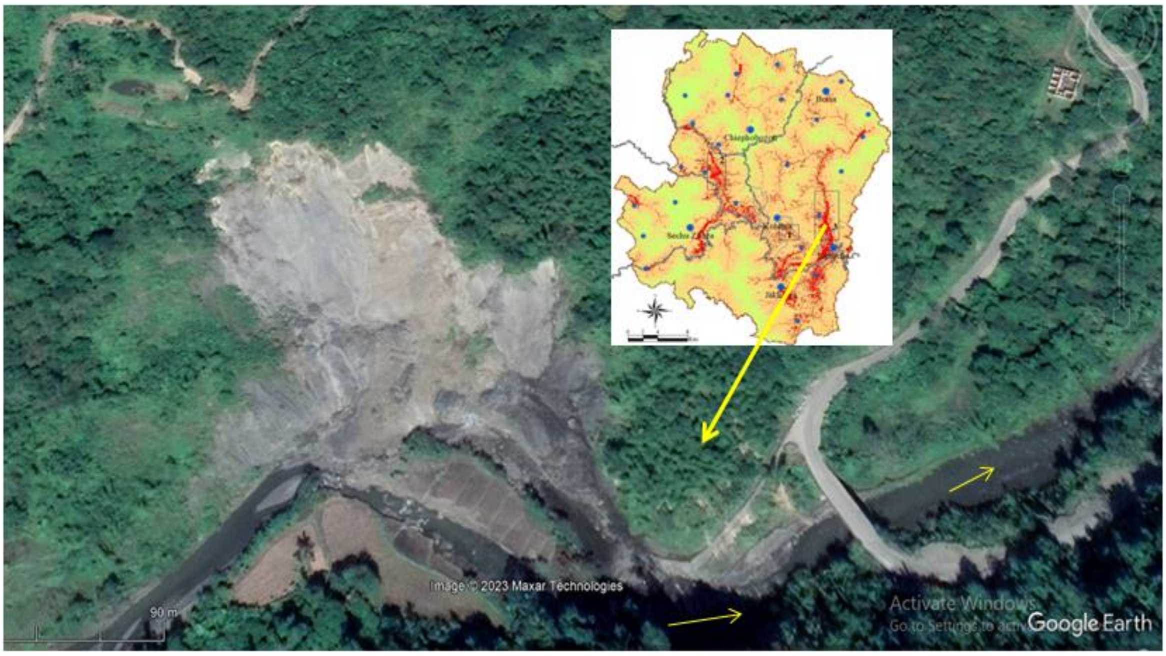


Figure 4.11: Flash flood-induced landslide, mass movement and slope failure in high-hazard zone.

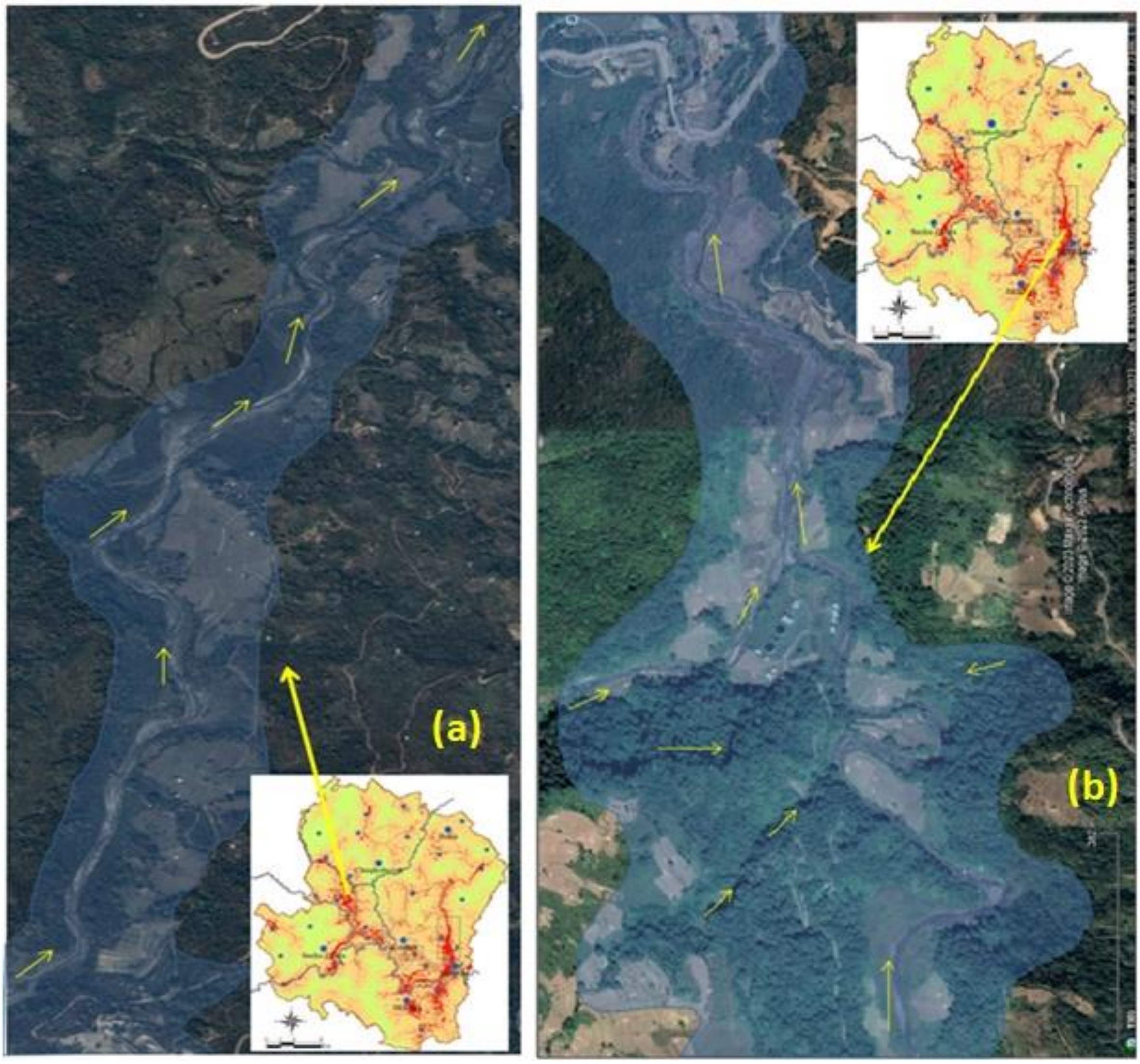


Figure 4.12: Agricultural land and settlements in floodplain area are under high flash flood disaster risk in Kohima district.

4.4. Climate Change in Kohima District

Climate change is widely recognized as a significant global concern, with the Earth's average temperature steadily rising at a pace of 0.01-0.30 degrees per year (Rosenzweig and Parry, 1994; Howden et al., 2007; Rawat, 2014; Rawat et al., 2017). The recent assessments from the Intergovernmental Panel on Climate Change (IPCC) in 2022 caution that climate change-induced natural disasters might impede or perhaps reverse the progress made in human development. Climate change is a natural cycle of the Earth's climate, but in recent decades, human activities have been speeding it up by releasing greenhouse gases. This has resulted in negative effects on weather, ecosystems, and economies worldwide (Adams et al., 1995; Darwin and Kennedy, 2000; Rawat et al., 2011). Existing research indicates that human-caused climate change is causing negative effects worldwide in various types of geo-ecological systems, including coastal, plain, desert, and mountainous regions (Parry et al., 1999; Porter and Semenov, 2005; Slingo et al., 2005; Lobell and Burke, 2010). Coastal regions see an increase in sea levels, intense cyclonic storms, and frequent episodes of heavy rainfall (Mearns et al., 1997; Fischer et al., 1996; John et al., 2005; Mohapatra et al., 2021). Desert ecosystems have been facing prolonged periods of little to no rainfall and significant shortages of water (Rosenzweig and Parry, 1994; Fischer et al., 1996; Kusi et al., 2023). Riverine areas have inundation and waterlogging issues in flat zones (Sadek, 2021). The mountain and its foothill zone have been experiencing severe weather events and resulting hydrological disasters. These include flash floods, river line floods, soil erosion, landslides, land subsidence, debris flow, and slope failure during the rainy season. In contrast, droughts occur during the summer season.

The Himalaya Mountain provides a diverse range of resources and benefits to humanity, including freshwater, carbon storage, biodiversity, forest products, agricultural and horticultural products, minerals, power, recreation possibilities, and more. Climate change poses a significant threat to all of these services from various angles (Hamilton, 1987; Easterling et al., 1993; Darwain, 1999; Rawat et al., 2007; 2007a; 2022; 2023). The fragile Himalaya Mountain system is currently at risk due to the negative effects of human-caused climate change, which has been greatly accelerated by various human and technological activities (Wheeler et al., 2000; Iglesias et al., 2000; 2007; Hansen and Jones, 2000; Challinor et al., 2005). Anthropogenic climate change has led to the occurrence of accelerated monsoon hydrological risks, as shown by Mearns et al. (1997), Katz and Brown (1992), and Jain et al. (1994). In order to address the negative effects of climate change and successfully implement sustainable adaptation strategies, it is crucial for governments, administrations, planners, and citizens to have a comprehensive understanding of the present condition and patterns of climate change at the local level, specifically within micro-climatic zones. Addressing these concerns, several groundbreaking studies (Valdiya and Bartarya, 1989; Tao et al., 2006; Sing, 2006; Rawat et al., 2012; 2012a; 2012b; Rawat, 2014 and Rawat et al., 2017) have been conducted in the central Himalaya region. However, there has been a notable absence of recognized studies in the eastern region of the Himalayas, specifically in the northeastern states of India. The area under study is located inside India's humid subtropical climatic zone (Ali et al., 1993). Nevertheless, as a result of notable variations in climate at different altitudes, which range from 204 meters to 2953 meters, the region may be classified into four specific micro-climatic zones: humid tropical, humid subtropical, temperate, and humid temperate. The presence of many climatic zones within Kohima district highlights its importance in comprehending climate change.

4.4.1. Rising average temperature: The average annual temperatures at different elevations have been compiled in table 4.5 and depicted in a figure 4.13 for the last three decades. The data suggest a steady rise in the average yearly temperature throughout the study region, with an annual increase of 0.13 degrees Celsius (equal to 0.62% each year). The temperature rise varies between 0.11 degrees Celsius per year (0.48% per year) for altitudes below 800 meters and 0.15 degrees Celsius per year (0.76% per year) for elevations over 2400 meters. Temperatures at elevations ranging from 800 meters to 2400 meters exhibit a varying rate of growth, ranging from 0.12 degrees Celsius per year (0.52% per year) to 0.14 degrees Celsius per year (0.72% per year).

4.4.2. Decreasing average rainfall: The mean annual rainfall over the research region has been analyzed and presented in table 4.5 and figure 4.13. These data show a decrease in average yearly rainfall at different elevations. The drop is recorded at an average annual rate of 9.55 centimeters (equal to 2.02% each year). The decline varies from a minimum of 7.60 centimeters per year (equivalent to a 1.85% annual drop) for altitudes below 800 meters, to a high of 10.44 centimeters per year (equivalent to a 2.09% annual decrease) for elevations over 2400 meters. The rate of rainfall reduction within the elevation range of 800 meters to 2400 meters varies from 8.40 centimeters per year (1.92% per year) to 10.24 centimeters per year (2.07% per year).

Table 4.5: Trends of annual mean temperature (°C) and rainfall (Cm) in four elevation zones

Year	Annual Mean Temperature (°C) and rainfall (Cm) by four elevation zones									
	Below 800m		800-1600m		1600-2400m		2400-3200m		Kohima district	
	Temp	Rainfall	Temp	Rainfall	Temp	Rainfall	Temp	Rainfall	Temp	Rainfall
1991	23.90	316.18	22.7	341.18	20.00	396.18	18.20	402.18	21.24	375.81
1992	24.45	411.75	23.25	436.75	20.55	493.75	18.75	499.75	21.79	472.13
1993	24.82	342.40	23.62	367.40	20.92	424.40	19.12	430.40	22.16	402.78
1994	25.15	316.46	23.95	341.46	21.25	398.46	19.45	404.46	22.49	376.84
1995	26.00	394.47	24.80	419.47	22.10	476.47	20.30	482.47	23.34	454.85
1996	26.52	282.79	25.32	307.79	22.62	364.79	20.82	370.79	23.86	343.17
1997	25.40	249.92	24.20	274.92	21.50	331.92	19.70	337.92	22.74	310.30
1998	27.40	264.22	26.20	289.22	23.50	346.22	21.70	352.22	24.74	324.60
1999	27.94	303.70	26.74	328.70	24.04	385.70	22.24	391.70	25.28	364.08
2000	26.64	321.81	25.44	346.81	22.74	403.81	20.94	409.81	23.98	382.19
2001	27.43	299.22	26.23	324.22	23.53	381.22	21.73	387.22	24.77	359.60
2002	27.23	283.93	26.03	308.93	23.33	365.93	21.53	371.93	24.57	344.31
2003	27.09	299.91	25.89	324.91	23.19	381.91	21.39	387.91	24.43	360.29
2004	27.07	313.58	25.87	338.58	23.17	395.58	21.37	401.58	24.41	373.96
2005	27.18	286.43	25.98	311.43	23.28	368.43	21.48	374.43	24.52	346.81
2006	27.07	260.44	25.87	285.44	23.17	342.44	21.37	348.44	24.41	320.82
2007	25.97	327.07	24.77	352.07	22.07	409.07	20.27	415.07	23.31	387.45
2008	25.87	326.71	24.67	351.71	21.97	408.71	20.17	414.71	23.21	387.09
2009	26.59	270.54	25.39	295.54	22.69	352.54	20.89	358.54	23.93	330.92
2010	26.04	327.06	24.84	352.06	22.14	409.06	20.34	415.06	23.38	387.44
2011	24.19	300.68	22.99	325.68	20.29	382.68	18.49	388.68	21.53	361.06
2012	24.04	264.27	22.84	289.27	20.14	346.27	18.34	352.27	21.38	324.65
2013	25.06	302.21	23.86	327.21	21.16	384.21	19.36	390.21	22.40	362.59
2014	24.38	265.73	23.18	290.73	20.48	347.73	18.68	353.73	21.72	326.11
2015	24.61	279.63	23.41	304.63	20.71	361.63	18.91	367.63	21.95	340.01
2016	25.84	302.93	24.64	327.93	21.94	384.93	20.14	390.93	23.18	363.31
2017	25.67	341.26	24.47	366.26	21.77	423.26	19.97	429.26	23.01	401.64
2018	25.79	330.39	24.59	355.39	21.89	412.39	20.09	418.39	23.13	390.77
2019	26.48	305.80	25.28	330.80	22.58	387.80	20.78	393.80	23.82	366.18
2020	26.15	297.50	24.95	322.50	22.25	379.50	20.45	385.50	23.49	357.88
2021	26.57	238.88	25.37	263.88	22.67	320.88	20.87	326.88	23.91	299.26
2022	27.55	235.55	26.55	260.55	24.45	317.55	22.72	323.55	25.35	295.93
Annual Change	**0.11**	**-7.60**	**0.12**	**-8.40**	**0.14**	**-10.24**	**0.15**	**-10.44**	**0.13**	**-9.55**
	0.48%	**-1.85%**	**0.55%**	**-1.92%**	**0.72%**	**-2.07%**	**0.80%**	**-2.09%**	**0.62%**	**2.02%**

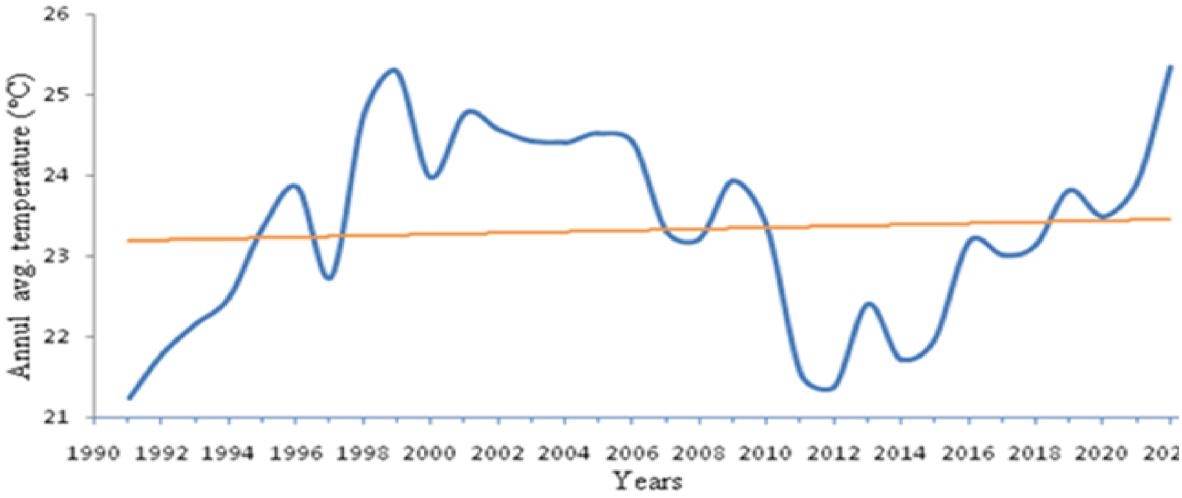


Figure 4.13: Annual trends of average temperature in Kohima district during last three decades (1991-2022).

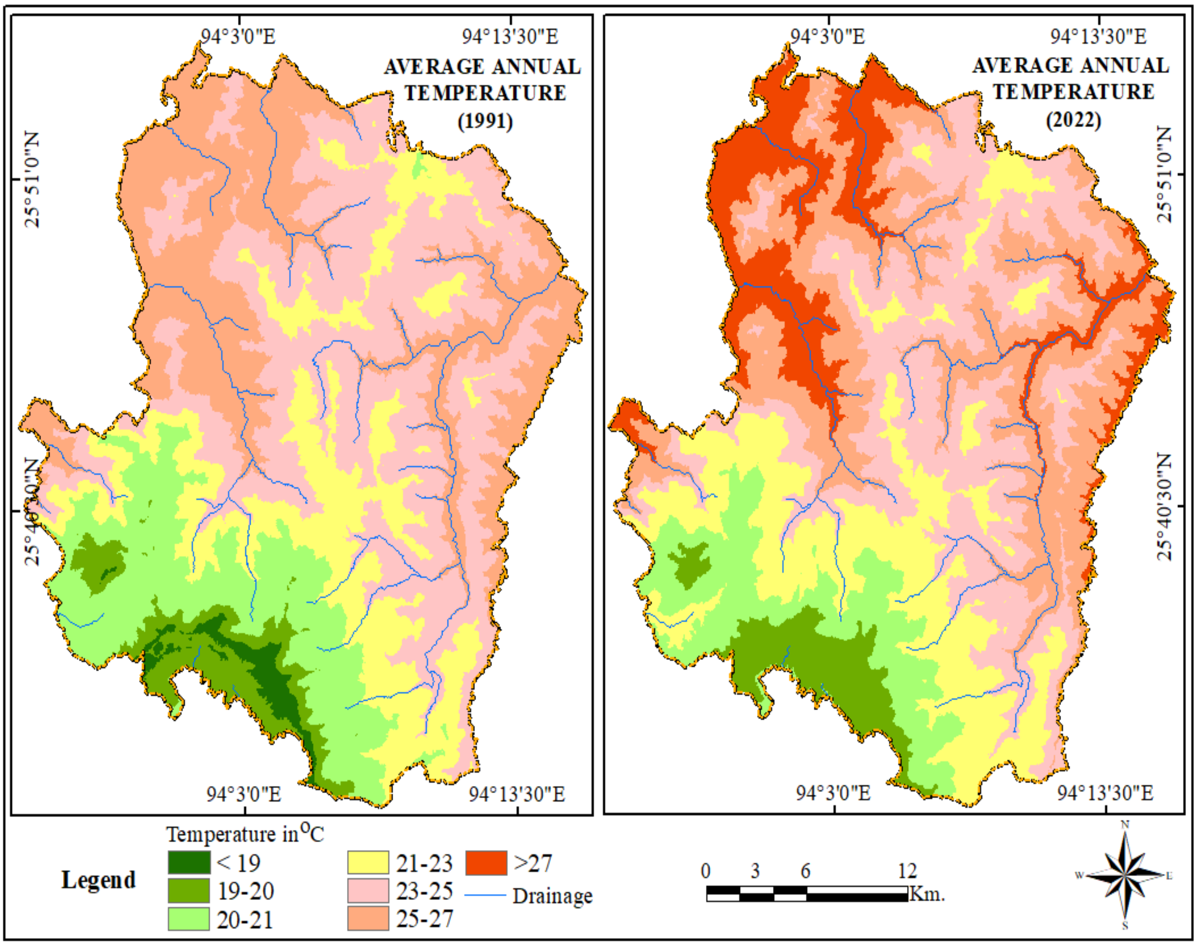


Figure 4.14: Spatial temporal change of annual average temperature during 1991-2022.

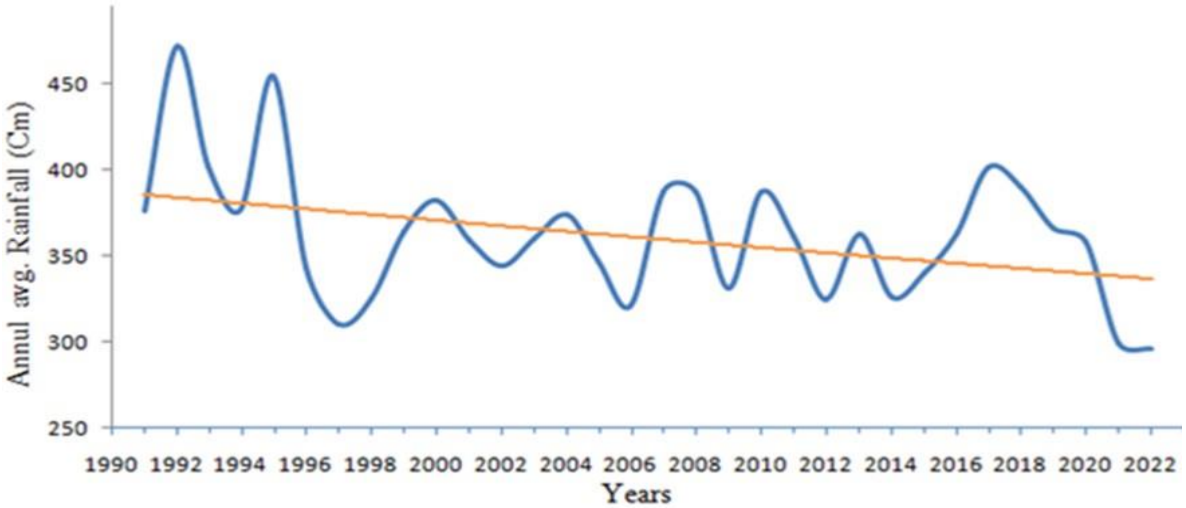


Figure 4.15: Annual trends of average rainfall in Kohima district during last three decades (1991-2022).

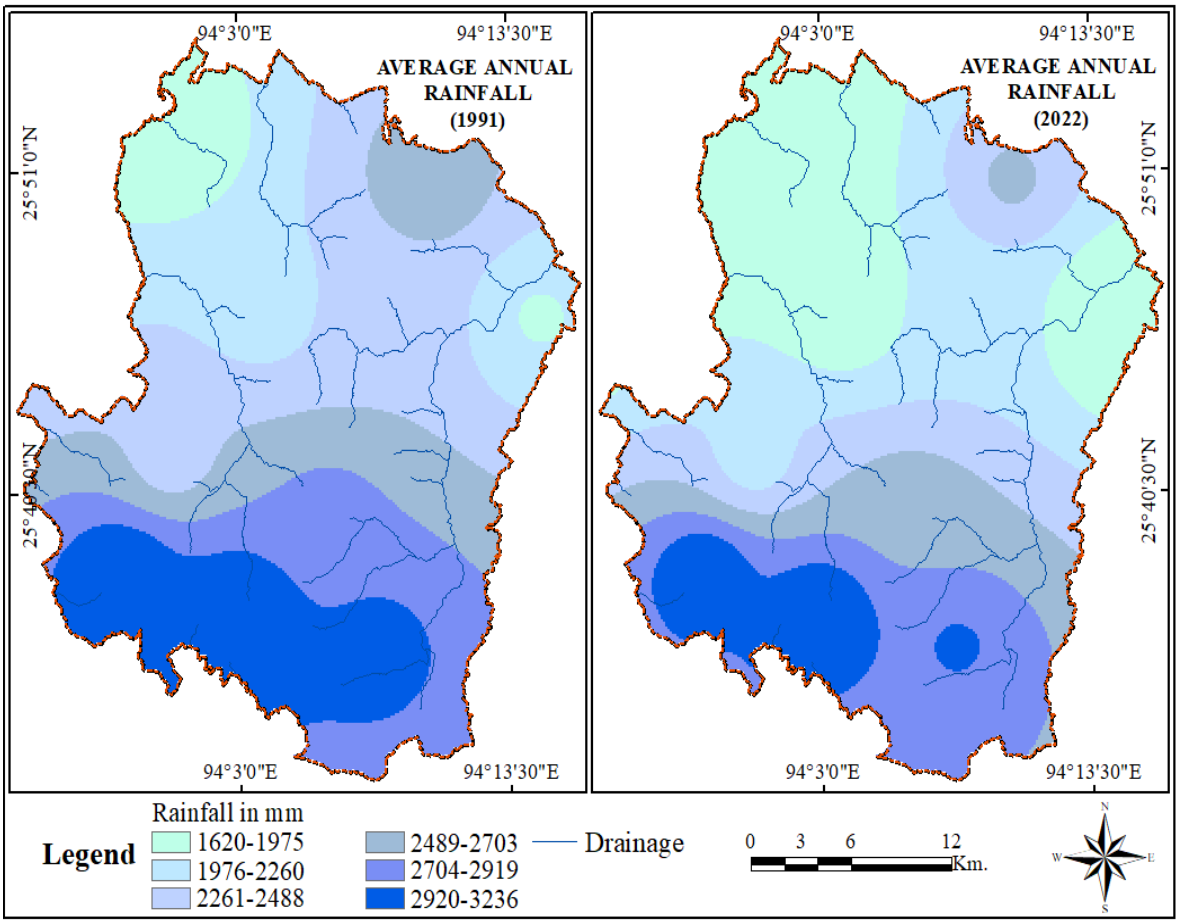


Figure 4.16: Spatial temporal change of annual average rainfall during 1991-2022

Table 4.6: Trends of annual mean rainy days and extreme rainfall events at four elevation zones (climatic zones) of Kohima district of Nagaland, India.

Year	Annual Mean rainy days and extreme rainfall events (in number)								Average of Kohima district	
	Below 800m		800-1600m		1600-2400m		2400-3200m			
	Rainy days	Extreme Events	Rainy days	Extreme Events	Rainy days	Extreme Events	Rainy days	Extreme Events	Rainy days	Extreme Events
1991	160	8	168	8	198	10	208	12	186	10
1992	159	8	167	8	196	11	208	11	185	10
1993	159	9	166	9	194	12	207	12	184	10
1994	158	9	165	9	193	12	207	10	183	11
1995	157	9	165	10	191	13	206	13	182	11
1996	157	10	164	10	189	14	206	14	181	12
1997	156	10	163	11	188	15	206	16	180	13
1998	156	11	162	11	186	16	205	17	179	14
1999	155	11	161	12	184	18	205	18	178	15
2000	154	11	161	12	183	19	204	19	177	16
2001	154	12	160	13	181	20	204	21	176	17
2002	153	12	159	14	179	22	203	23	175	18
2003	152	13	158	14	178	23	203	24	175	19
2004	152	13	157	15	176	25	203	26	174	21
2005	151	14	157	16	174	27	202	28	173	22
2006	151	14	156	17	173	29	202	30	172	24
2007	150	15	155	17	171	31	201	33	171	25
2008	149	16	154	18	170	33	201	35	170	27
2009	149	16	154	19	168	36	201	38	169	29
2010	148	17	153	20	167	38	200	41	168	31
2011	148	18	152	21	165	41	200	44	168	33
2012	147	21	151	22	164	44	199	47	167	36
2013	146	19	150	23	162	47	199	51	166	37
2014	146	20	150	25	161	51	199	55	164	40
2015	145	21	149	26	159	54	198	59	164	43
2016	145	18	148	27	158	58	198	64	163	45
2017	144	22	147	28	157	62	197	69	162	48
2018	144	23	147	30	155	67	197	74	162	52
2019	143	24	146	31	154	72	197	80	160	55
2020	142	27	145	33	152	77	196	86	159	59
2021	142	26	145	35	151	83	196	93	159	63
2022	141	28	144	36	148	89	150	98	147	67
Annual Change	**-0.60**	**1**	**-0.78**	**2**	**-1.61**	**3**	**-1.87**	**4**	**-1.23**	**3**
	-0.38%	**4.10%**	**-0.46%**	**5.15%**	**-0.81%**	**7.30%**	**-0.90%**	**7.70%**	**-0.67%**	**6.15%**

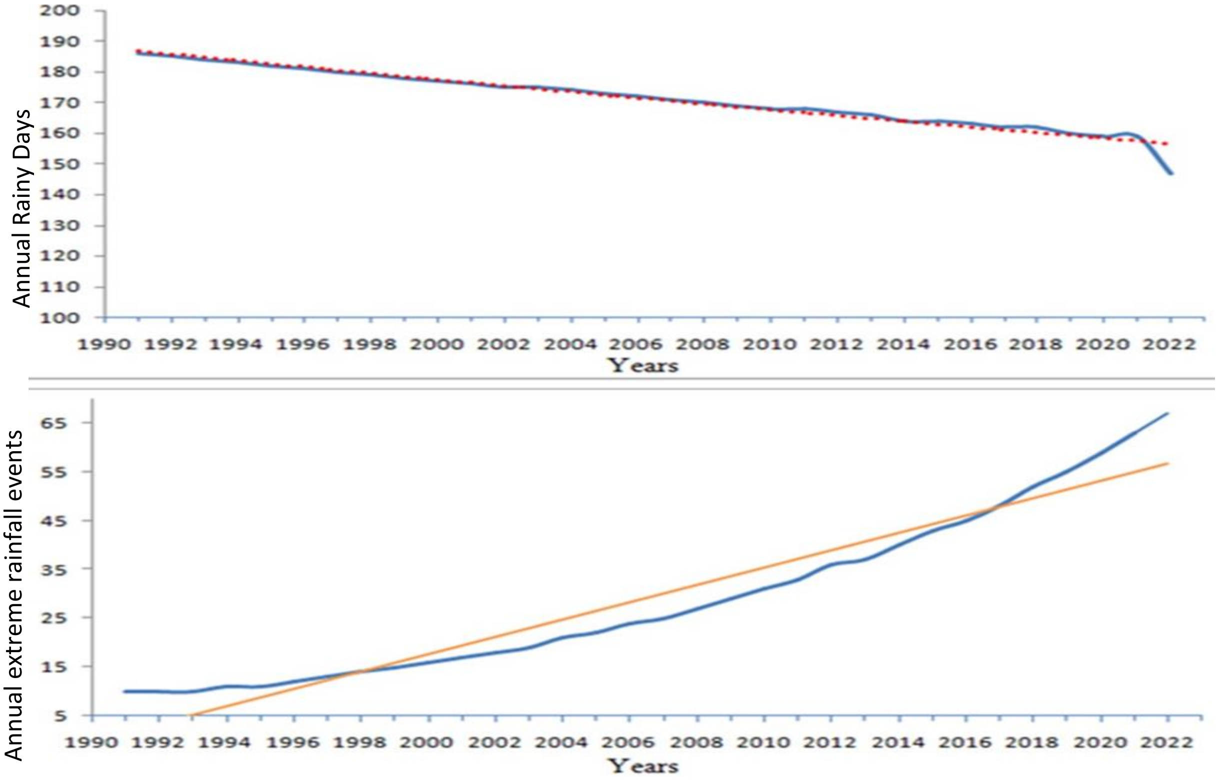


Figure 4.17: Annual trends of (c) rainy days and (b) extreme rainfall events in Kohima district during last three decades (1991-2022).

4.4.3. Decreasing Rainy Days: The average yearly rainy days at different elevations are summarized in table 4.6 and seen in figure 4.17. The data suggest a drop in the yearly average of rainy days in the study region, with an average reduction of 1.23 days per year (corresponding to a 0.67% loss every year). The decrease varies from a minimum of 0.60 day annually (0.38% annually) for elevations below 800 meters to a high of 1.87 days annually (0.90% annually) for elevations over 2400 meters. The rate of decline in rainy days within the elevation range of 800 meters to 2400 meters varies from 0.78 days per year (0.46% per year) to 1.61 days per year (0.81% per year).

4.4.4. Increasing extreme rainfall events: The table 4.6 displays the average annual severe rainfall events at various elevations, whereas figure 4.17 provides a visual representation of this data. The data indicates a rise in annual severe rainfall events in the study region, with an average increase of 2 occurrences per year (equal to a 6% yearly rise). The rate of growth varies depending on the elevation, ranging from a minimum of 1 event per year (4.10% per year) for altitudes below 800 meters to a maximum of 3 occurrences per year (7.70% per year) for elevations over 2400 meters. In contrast, at elevations ranging from 800 meters to 2400 meters, the occurrence of intense rainfall events ranges from 1 event per year (5.15% annually) to 3 occurrences per year (7.30% annually).

4.4.5. The expansion of micro-climatic zones: Examination of meteorological data from over thirty years reveals that each of the four micro-climatic zones has seen temperature rises and moved towards higher altitudes at an average yearly rate of 5.83 meters (refer to table 4.7). The rate varies depending on the climate zone. It is lowest in the humid tropical zone at 3.33 meters per year and highest in the humid temperate zone at 8.33 meters per year. The humid subtropical zone has a rate of 5 meters per year, while the temperate climatic zone has a rate of 6.67 meters per year. As a result, the tropical to humid subtropical climatic zone has become larger, whereas the temperate to humid temperate zone has become smaller (see table 4.7 and figure 4.18).

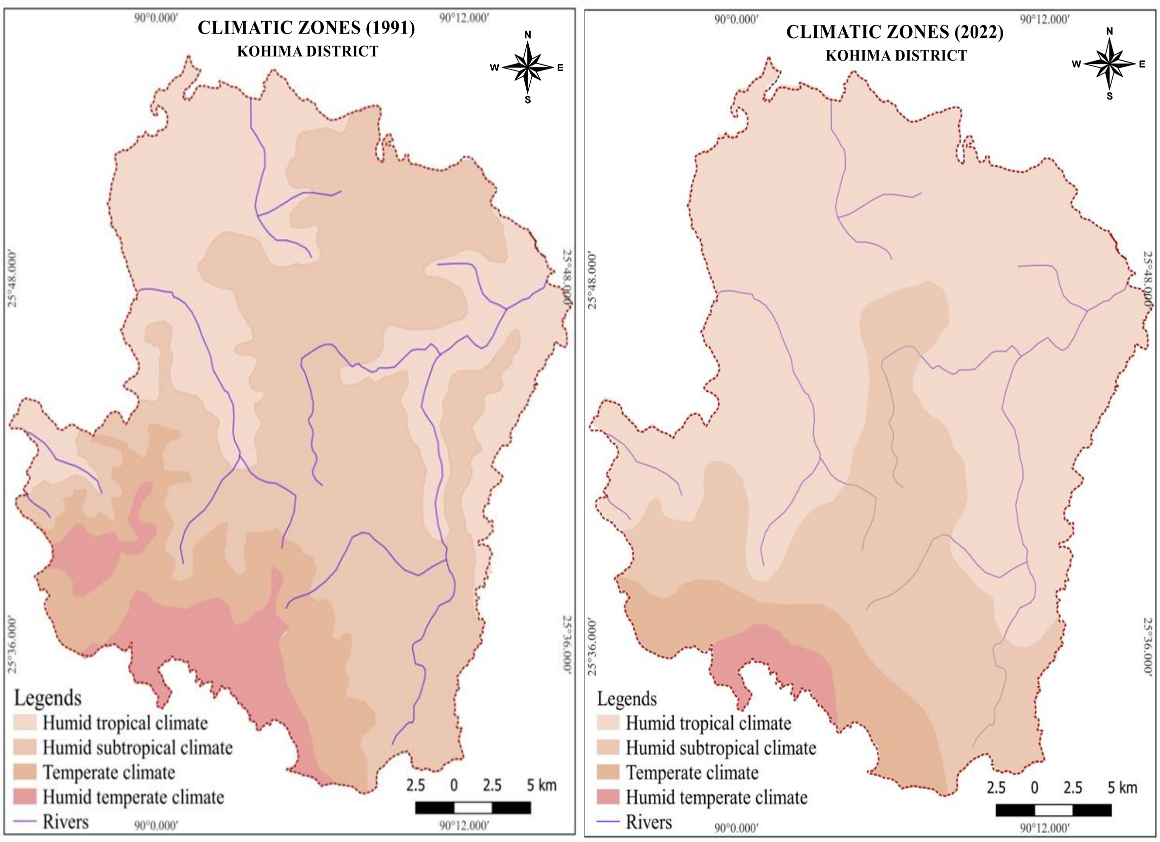


Figure 4.18: Spatial change in climatic zones in Kohima district, Nagaland

Table 4.7: Mounting climatic zones due to changing meteorological characteristics

Climatic Zones	Elevation (m)		Change in elevation (m)	
	1991	2022	1991-2022	Annual rate
Humid tropical	Below 800	Below 900	100	3.33
Humid sub-tropical	800-1600	900-1750	150	5.00
Humid temperate	1600-2400	1750-2600	200	6.67
Humid sub temperate	2400-3200	2600-3450	250	8.33
Kohima district Average			**175**	**5.83**

4.5. Climate Change and Geo-hydrological Hazards in Kohima District:

Climate change is widely acknowledged as a major worldwide problem, supported by the continuous rise in the Earth's average temperature, which increases by around 0.01 to 0.30 degrees each year (Rosenzweig and Parry, 1994; Howden et al., 2007; Rawat, 2014; Rawat et al., 2017). The Intergovernmental Panel on Climate Change (IPCC, 2022) has issued several publications warning that climate change-induced natural disasters might hinder or possibly undo the advancements made in human civilization. Climate change, although occurring naturally, has been expedited by human activities in recent decades due to the release of greenhouse gases. This has resulted in negative impacts on weather patterns, ecosystems, and global economies worldwide (Adams et al., 1995; Darwin and Kennedy, 2000; Rawat et al., 2011). An analysis of current studies emphasizes the extensive negative impacts of human-caused climate change on different geo-ecological systems worldwide, such as coastal, plain, desert, and mountainous regions (Parry et al., 1999; Porter and Semenov, 2005; Slingo et al., 2005; Lobell and Burke, 2010). Coastal regions are currently facing the consequences of increasing sea levels, strong cyclonic storms, and increasingly regular episodes of heavy rainfall (Mearns et al., 1997; Fischer et al., 1996; John et al., 2017; Mohapatra et al., 2021). Desert ecosystems are currently facing the challenges of prolonged periods of drought and severe water shortages (Rosenzweig and Parry, 1994; Fischer et al., 1996; Kusi et al., 2023). On the other hand, plain regions are experiencing concerns related to excessive floods and waterlogging caused by rivers (Sadek, 2021). In mountainous areas and their lower slopes, severe weather events have resulted in hydrological disasters such as sudden floods, river floods, soil erosion, landslides, land sinking, debris flows, and slope failures during the rainy season, as well as droughts during the summer season.

Kohima district is notorious for a substantial occurrence of geo-hydrological hazards, including slope collapse, landslide, land subsidence, land creeping, flash floods, and cloud bursts, which are exacerbated by climate change, as mentioned before. Therefore, a specific part of the research has been focused on comprehending the many monsoonal geo-hydrological dangers that are widespread in the Kohima area.

4.5.1. Methodology

Development of GIS Database: By employing GIS and remote sensing techniques, we gathered crucial primary data on the geoenvironmental features of the terrain. This data includes information on drainage patterns, slope, and relief, which was obtained using digital elevation models. The GIS maps underwent thorough validation through lengthy fieldwork and were ultimately approved for use as primary data. In order to carry out this important operation, satellite data from STRM and Google Earth, obtained from their respective platforms, were aligned and registered within the GIS framework. This was done by using Survey of India topographical sheets (83G/13, 83G/14, 83K/1, 83K/2, 83K/5) at a scale of 1:50000.

Climate Data Analysis: A total of 20 stations located in different areas within the research region were used to collect meteorological data from 1991 to 2022. This dataset consists of 10 terrestrial stations, which are collectively operated by the Nagaland state government (encompassing departments such as forest, soil conservation, and irrigation) and the Indian Meteorological Department (IMD). In addition, the other 10 stations depend on satellite-derived data obtained from NASA's Earth Observing System Data and Information System (EOSDIS) and NASA Power Data Access Viewer (accessible at https://power.larc.nasa.gov/data-access-viewer/).

Geospatial Analysis of Climate Change and Monsoon Geo-Hydrological Hazards: In order to analyze the yearly frequency and patterns of monsoon-related dangers (such as cloud bursts, floods, land creep, land subsidence, landslides, and slope failures), comprehensive field surveys were carried out to generate spatial distribution maps for each year over the past thirty years. In addition, data from disaster databases maintained by well-known international institutions such as EM-data, SAARC, and NIDM were gathered and examined. The years 1997 and 2022 were chosen to evaluate changes and trends in monsoon hazards, such as cloud bursts, floods, land creep, land subsidence, landslides, and slope failures, in relation to the impacts of climate change. 1997 represents the lowest annual occurrence of these hazards, while 2022 represents the highest. In order to do this, a grid map of 10 square kilometers was superimposed onto the spatial distribution maps for the years 1997 and 2022, resulting in the creation of hazard zone maps for each corresponding year. The geographic variations in monsoon hazard zones over the past three decades were calculated by superimposing both hazard zone maps.

4.5.2. Increasing monsoonal hydrological hazards in Kohima district

Climate change impacts on monsoon-related hydrological risks entail alterations in humid tropical and subtropical climatic conditions, such as heightened temperatures, accelerated evaporation rates, prompt cloud formation and dissipation, uneven distribution of rainfall, and intensified instances of extreme rainfall. These alterations are causing the migration of these circumstances to greater heights, hence intensifying hydrological risks during the monsoon period. The dangers encompass cloud bursts, increased surface runoff, abrupt flash floods, riverine flooding, soil erosion, land creep, subsidence, land fissures, rockfalls, debris flows, landslides, and slope collapses.

The increasing frequency of hydrological concerns associated with the monsoon (table 4.8) depicts the frequency of monsoonal hydrological events during the last three decades. During this era, a grand number of 4706 events took place. Out of them, cloud bursts, floods, and land creeping incidents were 1% (60 events), 18% (854 events), and 22% (1025 events) correspondingly. In addition, the occurrence of land subsidence, landslides, and slope collapses accounted for 25% (1196 occurrences), 29% (1366 events), and 4% (205 incidents) correspondingly. Upon analyzing the historical data spanning from 1991 to 2022, it was discovered that the yearly frequency of hydrological risks varied from a minimum of 65 incidents in 1997 to a maximum of 342 incidents in 2022, representing an estimated fivefold increase (as seen in the Figure 4.19 and Table 4.8). These findings suggest that the frequency of monsoon-related hydrological hazards has been rising steadily at an annual rate of 8.94%, with different types of hazards showing varying rates of increase. Cloud bursts and slope failures have the lowest annual increase of 0.16%, while landslides have the highest annual increase of 2.58%. The rates of increase for floods, land creeping, and land subsidence are 1.84%, 2.26%, and 2.58% per year accordingly, as shown in Table 4.8. Figure 4.21 displays the spatial arrangement of hydrological hazard events associated to the monsoon on a yearly basis. The events shown correspond to the years 1997 and 2022, with the minimum and maximum events represented, respectively.

Table 4.8: Trends of monsoonal hydrological hazards in Kohima district of Nagaland state in northeast India (Source: Field survey, EM-DAT, SAARC, and NIDM).

Year	Main monsoonal hydrological hazards						
	Cloud burst	Flood events	Land creep	Land subsidence	Landslide events	Slope failure	Total annual
1991	0	14	17	20	22	3	76
1992	1	18	22	25	29	4	99
1993	0	12	14	17	19	3	65
1994	1	16	19	22	26	4	88
1995	2	20	24	28	32	5	111
1996	1	15	18	21	24	4	83
1997	0	12	14	17	19	3	65
1998	1	13	16	18	21	3	72
1999	1	14	17	20	22	3	77
2000	1	15	18	21	24	4	83
2001	0	16	19	22	26	4	87
2002	1	17	20	24	27	4	93
2003	1	18	22	25	29	4	99
2004	1	15	18	21	24	4	83
2005	2	20	24	28	32	5	111
2006	1	22	26	31	35	5	121
2007	3	23	28	32	37	6	128
2008	2	20	24	28	32	5	111
2009	1	26	31	36	42	6	142
2010	5	28	34	39	45	7	157
2011	2	25	30	35	40	6	138
2012	1	33	40	46	53	8	181
2013	3	34	41	48	54	8	188
2014	2	36	43	50	58	9	198
2015	2	30	36	42	48	7	165
2016	3	41	49	57	66	10	226
2017	3	38	46	53	61	9	210
2018	2	47	56	66	75	11	258
2019	4	51	61	71	82	12	281
2020	3	45	54	63	72	11	248
2021	5	58	70	81	93	14	321
2022	5	62	74	87	99	15	342
Gross Total	60	854	1025	1196	1366	205	4706
	1%	18%	22%	25%	29%	4%	100%
Annual Trend	**1**	**2**	**2**	**2**	**3**	**1**	**9**
	0.16%	**1.61%**	**1.84%**	**2.26%**	**2.58%**	**0.39%**	**8.94%**

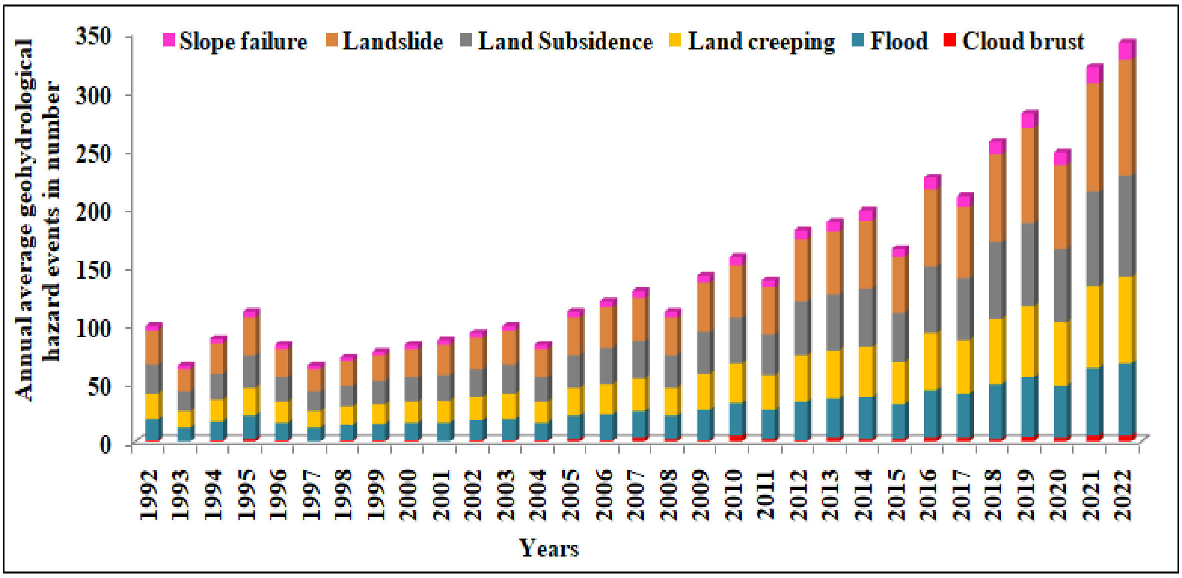


Figure 4.19: Annual monsoon hazard events and its trend in Kohima district of Nagaland state in northeast India during the last three decades.

A comparative analysis of geospatial distribution maps comparing the occurrence of monsoon hydrological hazard events in 1997 (with the fewest occurrences in a year) and 2022 (with the highest occurrences in a year) demonstrates that various types of monsoon-related hydrological hazards, such as cloud bursts, floods, land creeping, land subsidence, landslides, and slope failures, are not limited to specific areas but are widespread across the region. This contributes to the vulnerability of the region to specific hazards in terms of its geo-environmental conditions. The geographical pattern of monsoon hydrological hazards leads to the enlargement of areas with extremely high levels of risk, while a considerable fraction of areas with low and moderate risk are transformed into areas with moderate and high risk accordingly (Figure 4.21). An examination of attribute data from the monsoon hydrological hazard zone maps for 1997 and 2022 indicates that the area classified as very high danger zones has increased by 42% (411.16 km^2) between 1997 and 2022, with an annual growth rate of 1.68% (16.45 km^2) (Table 4.9). The low, moderate, and high danger zones have decreased by 9% (88.11 km^2), 10% (97.90 km^2), and 23% (225.16 km^2) respectively. The yearly reduction rates for these zones are 0.36% (3.52 km^2), 0.40% (3.92 km^2), and 0.92% (9.01 km^2) respectively (Table 4.9).

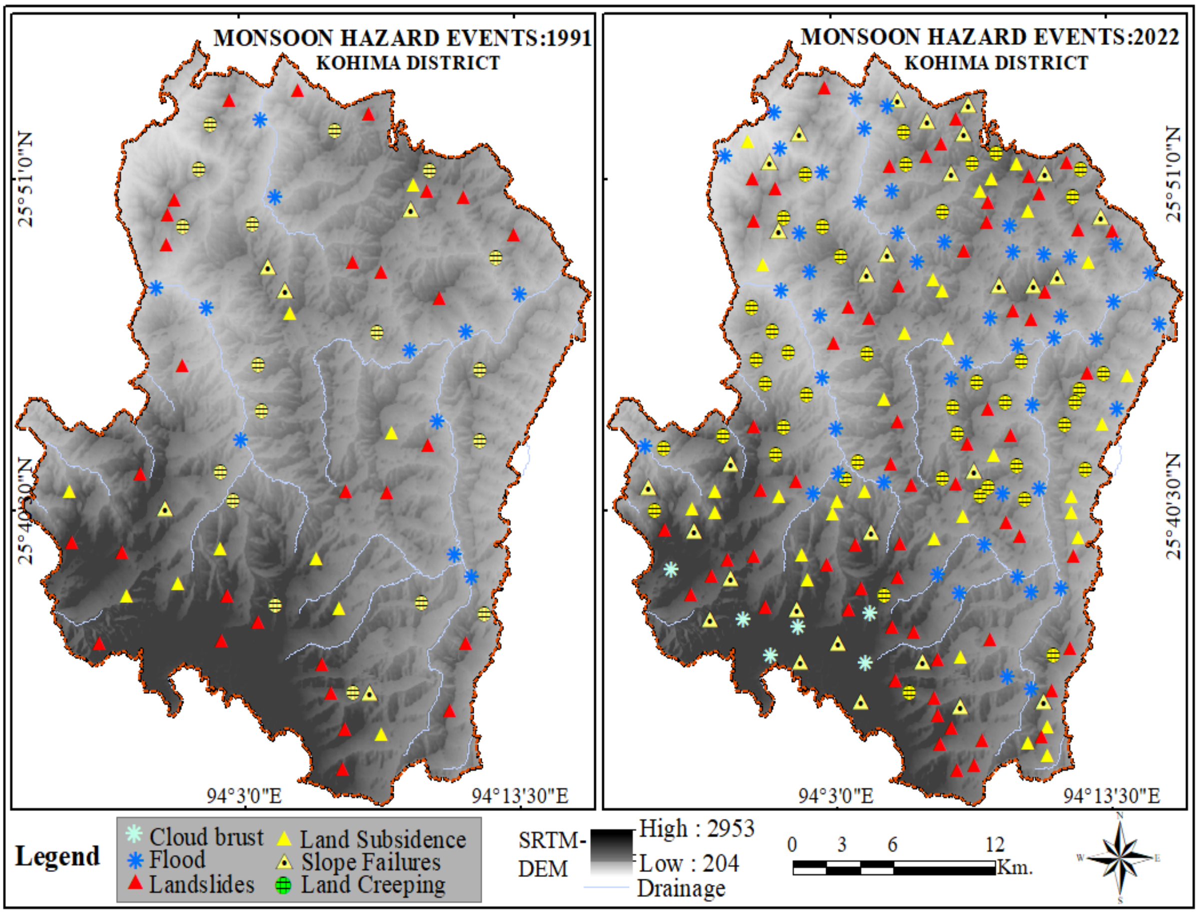


Figure 4.20: Spatial distribution of annual monsoon hazard events for the year 1997 and year 2022 in Kohima district, Nagaland, India.

Table 4.9: Sprawling monsoon geohydrological hazard zones in Kohima district, Nagaland, India.

Monsoon Hazard events/10km²	**Hazard Potential**	**Area under respective hazard zones**				**Changes**			
		1997		**2022**		**1991-2022**		**Annual**	
		Km²	**%**	**Km²**	**%**	**Km²**	**%**	**Km²**	**%**
Below 5	Low	146.84	15	58.74	6	-88.11	-9	-3.52	-0.36
5-10	Moderate	176.21	18	78.32	8	-97.90	-10	-3.92	-0.40
10-15	High	430.74	44	205.58	21	-225.16	-23	-9.01	-0.92
Above 15	Very high	225.16	23	636.32	65	411.16	42	16.45	1.68
Total		**978.96**	**100**	**978.96**	**100**		**-**	**-**	**-**

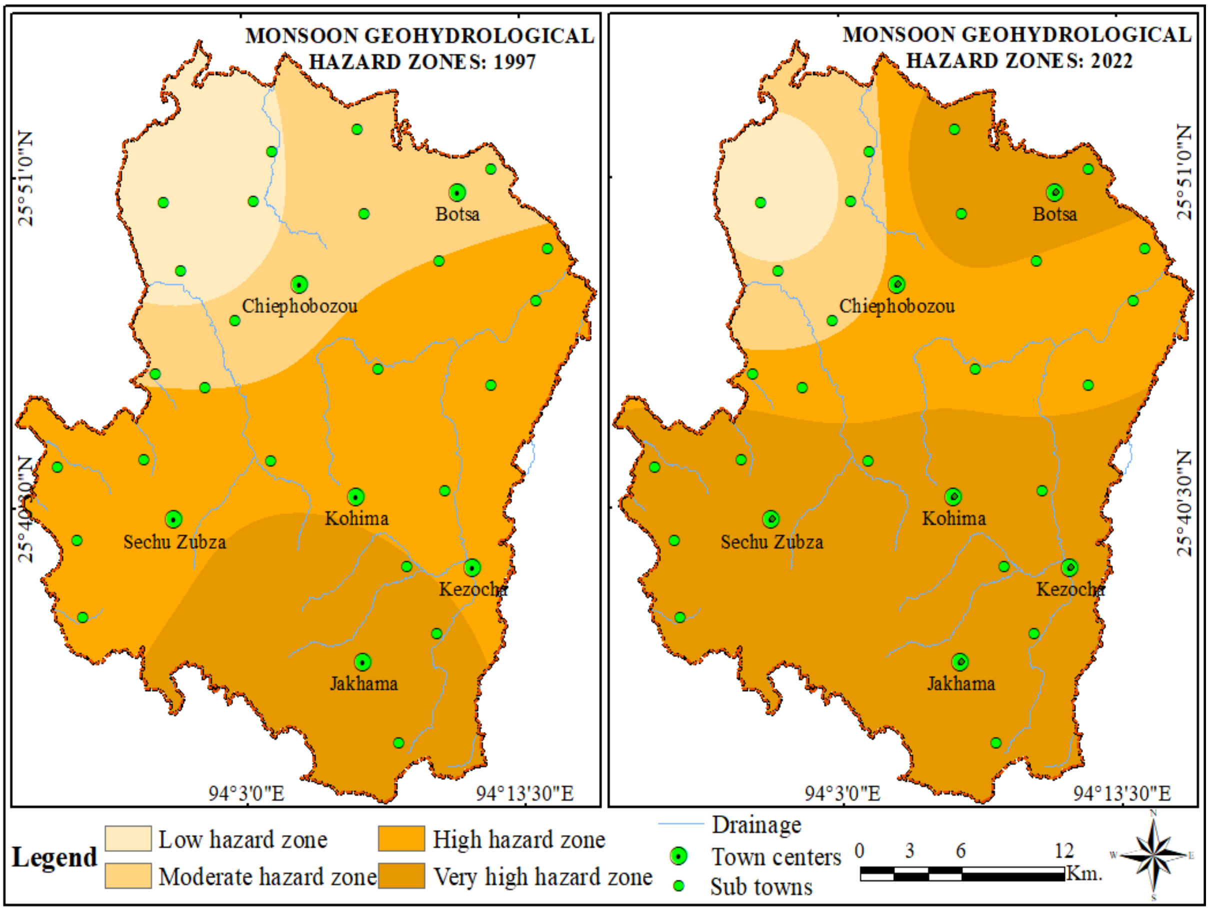


Figure 4.21: Monsoon hydrological hazard zones for the year 1997 and year 2022 of Kohima district, Nagaland, India.

The results indicate that the Kohima district of Nagaland state in northeast India is experiencing a significant increase in temperature, evaporation loss, and a decrease in rainfall and rainy days compared to the global average. These changes are primarily caused by human activities, such as, alterations in land use, deforestation, rapid unplanned urbanization, and technological intervention. (Rawat et al., 2013, 2013a, and 2017) These elements contribute to the exacerbation of undesirable effects caused by rapid climate change, such as the rise in intense rainfall events, rain-triggered landslides, gradual land sinking, debris flow, and slope collapses. The study area, as well as other parts of the Himalaya and the rest of the world, are currently witnessing the accelerated effects of human-induced climate change. This phenomenon, along with its harmful consequences, has been extensively studied in various ecological systems, as highlighted by pioneering research. Arekhi et al. (2012) conducted a case study in Iran using geospatial technology to examine the effects of accelerated climate change on soil loss and erosion. John et al. (2017) conducted a case study in southern Kerala, SW India to investigate the negative impacts of climate change on coastal ecosystems. Mohallel and Gomaa (2017) conducted a study on the effects of groundwater changes on the environment in relation to the impacts of climate change in the city of west Qena, Egypt. Meshram et al. (2017) assessed soil erosion in relation to the impacts of climate change. Rajimol et al. (2017) investigated the degradation of a tropical estuary caused by human interference. Brahim et al. (2020) examined the correlation between changing climatic data and the susceptibility to water erosion using the RUSLE model in a representative watershed in Northeast Morocco. Aithal et al., 2019 asserted that the unanticipated growth of cities and the expansion of industries have led to climate change in and around major cities in India. In their work on spatial modeling of flood susceptibility, Meliho et al. (2021) have highlighted the role of human activity in exacerbating flood dangers caused by climate change. They employed machine learning techniques to analyze this phenomenon. Chakraborty and Biswas (2021) conducted a research on the effects of intense rainfall events on the flow of rivers in hilly areas. Mohapatra et al. (2021) conducted an analysis of long-term rainfall trends in Odisha using high-resolution atmospheric data. Mostafa and Mohamed (2021) have compared the climate change data and seismotectonic in Aswan area, Egypt to investigate increasing geomorphological hazards; Sadek et al. (2021) have monitored extreme rainfall induced flash floods using modeling-based techniques and multi-source remotely sensed data in Ras Ghareb City, Egypt; Khanifar, (2022) has also assessed the impacts of extreme rainfall events on soil erosion based on DEM derivatives calculated using different polynomials; Alemu and Wubneh, (2023) have studied spatiotemporal trend variation of climate extreme over Lake Tana sub-basin, upper Blue Nile basin, Ethiopia and suggests trends of future climate in that particular area; Kassa and Meten (2023) have examined impacts of climate change on slope stability analysis using kinematic, limit equilibrium, and finite element models at Dessie town, northern Ethiopia; Khan et al. (2023) have carried out a comparative assessment of spatiotemporal variability in cryosphere and hydro-climatic regime of the Hunza, Astore and Shigar Basins (Hindukush-Karakoram–Himalaya Region) in Pakistan; Kusi et al. (2023) have evaluated the impacts of land use and climate changes on water ecosystem services in the Souss watershed, Morocco; Timilsina et al. (2023) have carried out a study on rainfall-runoff simulations in ungauged Fusre River basin, Nepal using HEC-HMS model; He et al., 2024 have examined slope stability under climate change impacts; Wang et al (2023) have studied mass movement due to excessive rain events in high slope areas.

References

Adams, R.M., Fleming, R.A., Chang, C.C., McCarl, B.A., & Rosenzweig, C. (1995). A Reassessment of the Economic Effects of Global Climate Change on US Agriculture. *Climatic Change* 30, 147-167

Agrawal, N., Gupta, L., Dixit, J., & Dash, S.K. (2023). Seismic risk assessment for the North Eastern Region of India by integrating seismic hazard and social vulnerability. *Sustainable and Resilient Infrastructure 8,* sup1, 102-132

Aithal, B.H., M C, C. & G, N. (2019). Assessing land surface temperature and land use change through spatio-temporal analysis: a case study of select major cities of India. *Arab J Geosci* **12**, 367. https://doi.org/10.1007/s12517-019-4547-1

Alemu, M.G., & Wubneh, M.A. (2023). Climate extreme indices analysis and spatiotemporal trend variation over Lake Tana sub-basin, upper Blue Nile basin, Ethiopia: under future climate change. *Arab J Geosci* 16: 660. https://doi.org/10.1007/s12517-023-11752-z

Ali, S., Sharma, M.R., & Maiteya, V.K. (1993). Climatic classification for building design in India.

Archit Sci Rev 36(1):31–34Fischer, G., Frohberg, K., Parry, M.L., & Rosenzweig, C. (1996). Impacts of potential climate change on global and regional food production and vulnerability. In: *Downing, TE (eds) NATO ASI Series, Climate Change and World Food Security, 137. Springer, Berlin*

Arekhi, S., Niazi, Y., & Kalteh, A.M. (2012). Soil erosion and sediment yield modeling using RS and GIStechniques:a case study. *Iran Arab J Geosci* 5(2):285-296. https://doi.org/10.1007/s12517-010-0220-4

Belho, K., Rawat, M.S., & Rawat, P.K. (2023). GIS modelling to investigate environmental change and degradation in Kohima district of Nagaland, North East Hill region of India. *Environmental Monitoring and Assessme*nt. Accepted, in press

Belho, K., Rawat, M.S. & Rawat, P.K. (2024). Anthropogenic climate change accelerating monsoon hydrological hazards in Northeastern Himalayan region of India: geospatial approach. *Arab J Geosci* 17, 67. https://doi.org/10.1007/s12517-024-11871-1

Balamurugan, G., Ramesh, V., & Touthang, M. (2016). Landslide susceptibility zonation mapping using frequency ratio and fuzzy gamma operator models in part of NH-39, Manipur, India. *Natural Hazards*, 84 (1), 465–488

Brahim, B., Meshram, S.G., & Abdallah, D. (2020). Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). *Arab J Geosci* 13: 1153. https://doi.org/10.1007/s12517-020-06079-y

Chakraborty, S., & Biswas, S. (2021). Simulation of flow at an ungauged river site based on HEC-HMS model for a mountainous river basin. *Arab J Geosci* 14(20):2080. https://doi.org/10.1007/s12517-021-08385-5

Challinor, A.J., Wheeler, T.R., Craufurd, P.Q., & Slingo, J.M. (2005). Simulation of the impact of high temperature stress on annual crop yields. *Agricultural and Forest Meteorology* 135: 180-189

Darwin, R., & Kennedy, D. (2000). Economic effects of CO2 fertilization of crops: transforming changes in yield into changes in supply. *Environmental Modeling and Assessment* 5 (3):157–168

Darwin, R. (1999). A farmer's view of the Ricardian approach to measuring agricultural effects of climatic change. Climatic Change, 41: 371-411 watershed, Morocco. *Arab J Geosci* 16: 126. https://doi.org/10.1007/s12517-023-11206-6

Doerr, A.H. (1990). Fundamentals of physical geography (3rd Ed.), Iowa: Wm C. Browers Publishers

Easterling, W.E. III., Crosson, P.R., Rosenberg, N.J., McKenny, M.S., Katz, L.A., & Lemon, K.M. (1993). Agricultural Impacts of and Responses to Climate Change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region. *Climatic Change* 24: 23-61

EM-DAT (Emergency Events Database). https://www.emdat.be/

Fischer, G.M., Shah, F., Tubello, J., van Veldhuizen. (2005). Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990-2080. *Philosophical Transactions of Royal SocietyB* 360: 2067-83

Gupta, L., Agrawal, N., Dixit, J., & Dutta, S. (2022). A GIS-based assessment of active tectonics from morphometric parameters and geomorphic indices of Assam Region, India. *Journal of Asian Earth Sciences X* 8, 100-115, https://doi.org/10.1016/J.JAESX.2022.100115

Hamilton, L.S. (1987). What are the impacts of Himalayan deforestation on the Ganges-Brahmaputra lowland and delta? Assumptions and facts *Mountain Research and Development*7:256-263

Hansen, J.W., & Jones, J.W. (2000). Scaling-up crop models for climate variability applications. *Agricultural Systems* 65, 43-72 (2000)

He, L., Zhao, Y., & Njamba, B. (2024). Slope stability calculation based on sparrow search algorithm and Monte Carlo simulation. *Arab J Geosci* 17: 5. https://doi.org/10.1007/s12517-023-11799-y

Howden, M.J.F., Soussana, F., Tubiello, N., Chhetri, M., Dunlop, H., & Meinke. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19691-19696.

IPCC (2022) Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

Iglesias, A., Garote, L., Flores, F., & Moneo, M. (2007b). Challenges to manage the risk of water scarcity and climate change in the Mediterranean. *Water Resources Management* 21:227-288

Iglesias, A., Rosenzweig, C., & Pereira, D. (2000). Prediction spatial impacts of climate in agriculture in Spain. *Global Environmental Change* 10:69–80

Jain, S.K., Kumar, S., & Varghese, J. (1994). Estimation of soil erosion for a Himalayan watershed using GIS technique. *Geol. Soc. London* 151:217-220

John, S.E., Rajimol, T.R., & Mohan, S.V. (2017). Environmental degradation of a tropical estuary due to human interferences—a case study from southern Kerala, SW India. *Arab J Geosci* 10: 352. https://doi.org/10.1007/s12517-017-3112-z

Kassa, M., & Meten, M. (2023). Slope stability analysis using kinematic, limit equilibrium, and finite element models at Dessie town, northern Ethiopia. *Arab J Geosci* 16: 675.https://doi.org/10.1007/s12517-023-11783-6

Katz, R.W., & Brown, B.G. (1992). Extreme events in changing climate variability is more important than averages. *Climatic Change* 21, 289-302

Khan, A., Farah, H., & Khan, S. (2023). Comparative assessment of spatiotemporal variability in cryosphere and hydro-climatic regime of the Hunza, Astore and Shigar Basins (Hindukush-Karakoram–Himalaya Region) in Pakistan. *Arab J Geosci* 16: 350. https://doi.org/10.1007/s12517-023-11440-y

Khanifar, J. (2022). Modeling of soil thickness based on DEM derivatives calculated using different polynomials. *Arab J Geosci* 15, 655.https://doi.org/10.1007/s12517-022-09941-3

Kusi, K.K., Khattabi, A., Mhammdi, N. (2023). Evaluating the impacts of land use and climate changes on water ecosystem services in the Souss. *Arabian Journal of Geosciences, volume 16, issue 2, publication number 126.* 10.1007/s12517-023-11206-6

Lobell, D.B., & Burke, M.B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology* 150: 1443-1452

Mearns, L.O., Rosenzweig, C., & Goldberg, R. (1997). Mean and variance change in climate scenarios: Methods, agricultural applications, and measures of uncertainty. *Climatic Change* 35: 367-396

Meliho, M., Khattabi. A., & Asinyo, J. (2021). Spatial modeling of flood susceptibility using machine learning algorithms. *Arab J Geosci* 14: 2243. https://doi.org/10.1007/s12517-021-08610-1

Meshram, S.G., Powar, P.L., & Singh, V.P. (2017). Modelling soil erosion from a watershed using cubic splines. *Arab J Geosci* 10:155–168. https://doi.org/10.1007/s12517-017-2908-1

Mohallel, S.A., & Gomaa, M.A. (2017). Studying the impacts of groundwater evolution on the environment, west Qena city, Egypt. *Arab J Geosci* 10: 372. https://doi.org/10.1007/s12517-017-3151-5

Mohapatra, J.B., Sahu, A.P., & Rout, B. (2021). Analysis of long-term rainfall patterns using high-resolution atmospheric data over Odisha. *Arab J Geosci* 14: 2223. https://doi.org/10.1007/s12517-021-08528-8

Mosley, M. P., & O'Loughlin, C. (1980). Slopes and slope processes. *Progress in Physical Geography: Earth and Environment,* 4(1), 97-106. https://doi.org/10.1177/030913338000400107

Mostafa, S.I., & Mohamed, A.E. (2021). A Seismotectonic studies in Aswan area, Egypt. *Arab J Geosci* 14: 2210. https://doi.org/10.1007/s12517-021-08608-9

Nakata, T. (1972). Geomorphic History and Crustal Movements of the Foot-hills of the Himalaya. *Tohoku University Science Reports, 7th Series, Japan* 22: 39–177.

NIDM (National Institute of Disaster Management). https://nidm.gov.in/

Pal, I., Nath, S.K., Shukla, K., Pal, D.K., Raj, A., Thingbaijam, K.K.S., & Bansal, B.K. (2008). Earthquake hazard zonation of Sikkim Himalaya using a GIS platform. *Nat Hazards* 45 (3), 333–377, https://doi.org/10.1007/s1106 9-007-9173-7

Parry, M.L., Fischer, C., Livermore, M., Rosenzweig, C., & Iglesias, A. (1999). Climate change and world food security: a new assessment. *Global Environmental Change* 9: S51–S67

Pirazizy, A. A. (1992). Environmental Geography and Natural Hazards. *Concept's International Series in Environment*

Pirazizy, A.A. (1989). Impact of Construction Activities on Environmental Changes in Kashmir Himalayas, In I, Mohan, *Environmental Issues and Programmes*, New World Environment Series, Ashish, New Delhi

Porter, J.R., & Semenov, M.A. (2005). Crop responses to climatic variation. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360, 2021-2035.nge 35: 367-396

Rawat, M. S. (2011). Environmental Geomorphology and Watershed Management. *Concept Publishing Company*, New Delhi (ISBN-13:978-81-8069-758-6)

Rawat, M. S. (2013). Sustainable development in Nagaland through integrated watershed management: A case study from Kiliki River Basin. *International Journal of Development Studies and Research,* Vol. 2, 60-80

Rawat, M. S. (2017). Environmental management in the headwater catchments of Kiliki river, Nagaland, North East India. *In: Ecosystem Services of Headwater Catchments (Eds. Krecek et. al.). Capital Publishing Company and co-published by Springer, International Publishing Company, Cham, Switzerland,* p. 105–115

Rawat, M. S. & Furkumzuk C. (2013a). Environmental management and sustainable development in the Kiliki watershed of Nagaland. *Indian Journal of Environmental Studies*, Vol. 01, (01), 26-42

Rawat, P. K., Tiwari, P.C., & Pant, C.C. (2011). Modeling of Stream Runoff and Sediment output for erosion hazard assessment in Lesser Himalaya; Need for sustainable land use plane using Remote Sensing and GIS: A case study. *Natural Hazards* 59:1277–1297

Rawat, P. K., Tiwari, P.C., Pant, C.C., Sharama, A.K., & Pant, P.D. (2011a). Spatial variability assessment of river-line floods and flash floods in Himalaya: A case study using GIS. *International journal of Disaster Prevention and Management* 12(2): 135-159

Rawat, P. K., & Sharma, A.K. (2012). Geo-diversity and its hydrological response in relation to landslide susceptibility in the Himalaya: a GIS-based case study, Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards 6:4, 229-251

Rawat, P. K., Tiwari, P.C., & Pant, C.C. (2012a). Geo-hydrological database modelling for integrated multiple hazards and risk assessment in Lesser Himalaya: GIS based case study. Natural Hazards 62:1233-1260

Rawat, P. K., Tiwari, P. C., & Pant, C.C. (2012b). Climate Change accelerating land use dynamic and its environmental and socio-economic risks in Himalaya: Mitigation through sustainable land use. *International Journal of Climate Change Strategy and Management*4(4):452-471

Rawat, P. K., & Pant, C.C. (2016). Environmental Geoinformatics: Theory to Practice for Disaster Management. *Lambert Academic Publishing*, Saarbrücken, Germany pp 229

Rawat, P. K., Pant, C.C., & Bisht, S. (2017). Geospatial analysis of climate change and emerging flood disaster risk in fast urbanizing Himalayan foothill landscape. *International Journal of Geomatics, Natural Hazard and Risks* 8(2): 418–447

Rawat, P. K., & Pant, B. (2023). Geoenvironmental GIS development to investigate Landslides and Slope Instability along Frontal zone of Central Himalaya. *International Journal of Natural Hazard Research* 3 (2): 196-204

Rawat, P. K., Pant, B., Pant, K., & Pant, P. (2022). Geospatial analysis of alarmingly increasing human-wildlife conflicts in Jim Corbett National Park's Ramnagar buffer zone: Ecological and socio-economic perspectives. *International Journal of Geoheritage and Parks* 10: 337–350

Rosenzweig, C., & Parry, M.L. (1994). Potential impact of climate change on world food supply. *Nature* 367:133–138

SAARC (South Asian Association for Regional Cooperation). https://www.saarc-sec.org/

Sadek, M., Li, X., & Mostafa, E. (2021). Monitoring flash flood hazard using modeling-based techniques and multi-source remotely sensed data: the case study of Ras Ghareb City, Egypt. *Arab J Geosci* 14: 2030. https://doi.org/10.1007/s12517-021-08341-3

Schmidhuber, J., & Tubiello, F.N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19703-19708

Schlenker, W., Hanemann, W.M., & Fisher, A.C. (2006). The impact of global warming on US agriculture: An econometric analysis of optimal growing conditions. *Review of Economics and Statistics* 88, 113-125

Semenov, M.A., & Porter, J.R. (1995). Climatic variability and the modeling of crop yields. *Agricultural and Forest Meteorology* 73, 265-283 (1995)

Sing, S.K. (2006). Spatial variability in erosion in the Brahmaputra basin: causes and impacts. *Curr Sci* 90(9):1272–1276

Slingo, J.M., Challinor, A.J., Hoskins, B.J., & Wheeler, T.R. (2005). Introduction: food crops in a changing climate. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360: 1983-1989

Tao, F.L., Yokozawa, M., Xu, Y.L., Hayashi, Y., & Zhang, Z. (2006). Climate changes and trends in phenology and yields of field crops in China, 1981-2000. *Agricultural and Forest Meteorology* 138, 82-92

Valdiya (1985). Accelerated erosion and landslide-prone zones in the Himalayan region. *In*: J.S. Singh (Ed) *Environmental Research in Himalaya*, Central Himalayan Environmental Association, Nainital, pp. 39–53

Valdiya, K.S., & Bartarya, S.K. (1989). Problem of mass-movement in part of Kumaun Himalaya. *Curr Sci* 58:486–491

Wang, C.X., Zhou, J.W., & Zhang, C.B. (2023). Failure mechanism analysis and mass movement assessment of a post-earthquake high slope. *Arab J Geosci* 16: 683. https://doi.org/10.1007/s12517-023-11737-y

Wheeler, T.R., Craufurd, P.Q., Ellis, R.H., Porter, J.R., & Prasad, P.V.V. (2000). Temperature variability and the yield of annual crops. *Agriculture Ecosystems & Environment* 82, 159-167

Management and Mitigation of Hazards: A review of Government and Community Programs

The effects of disasters are multifaceted and affect the personal, sociocultural, and economic spheres (Satendra, 2003). In addition to impeding developmental endeavors, they also hinder progress by demolishing projects and facilities (Bansal et.al., 1976). While disasters are unavoidable, their negative effects may be significantly minimized via the implementation of different mitigation programs and improved management techniques. Disaster management according to United Nations Office for Disaster Risk Reduction (UNDRR) refers to the systematic coordination and implementation of strategies aimed at preparing for, reacting to, and recovering from catastrophic events and mitigation refers to the reduction or elimination of the negative consequences of a disaster. The concept of Disaster management includes the following four factors:

i) **Prevention**: The United Nations International Strategy for Disaster Reduction (UNISDR) considers prevention as a priority. Disaster prevention refers to the proactive engagement in actions aimed at averting or mitigating possible negative consequences. These efforts are specifically intended to provide protection against the occurrence of catastrophes.

ii) **Preparedness**: As defined by the International Committee of the Red Cross (ICRC), Disaster Preparedness encompasses the actions and strategies used to anticipate and mitigate the impact of both natural and human-caused disasters. This is accomplished via doing research and strategic planning to anticipate and mitigate potential disaster-prone locations or regions. The aim is to avoid or minimize the effects of such catastrophes on vulnerable people, enabling them to successfully manage and overcome the challenges they may face. Implementing disaster preparation actions that include risk reduction strategies may effectively avert catastrophe circumstances and significantly contribute to preserving the greatest number of lives and livelihoods. This enables the afflicted community to quickly return to normality after a disaster.

iii) **Response/ Relief**: This stage primarily addresses urgent and short-term requirements. However, the distinction between this stage and the later recovery stage is not well-defined. Certain response measures, such as the provision of interim housing and water resources, may continue for a significant duration throughout the recovery phase. The basic objective of disaster response/relief is to promptly rescue individuals from imminent danger and provide necessary support to stabilize their bodily and emotional well-being. Response/Relief activities encompass rescue moving to a new location, providing necessary resources, provision of sustenance and hydration as well as emergency medical treatment, disease and disability prevention, restoring critical infrastructure such as telecommunications and transportation services and providing temporary shelter.

iv) **Rehabilitation:** Communities often remain vulnerable for an extended period even after the immediate crisis has ended. The activities included are as follows: Reconstructing infrastructure such as residential buildings, educational institutions, medical facilities, and transportation routes. Healthcare and rehabilitation development activities, such as the establishment of human resources for health, are being undertaken. Strategies and protocols to prevent or reduce the occurrence of similar circumstances in the future.

The Indian subcontinent is susceptible to earthquakes, cyclones, floods, and droughts. The Himalayan region experience avalanches, forest fires, and landslides and the Northeastern region is prone to earthquakes, soil erosion, flash floods, floods, landslides and forest fires (Prakash, 1994). Out of the 35 states and Union territories, 24 of them are susceptible to disasters. The magnitude of the disasters in the country necessitates a nationwide response mechanism, which should include predetermined allocation of roles and functions for different institutions at the central, state, and district levels. This will ensure effective management before, after, and during the disaster (Satendra, 2001). Therefore, in light of the significant loss of life, property, and resources caused by frequent disasters, the Indian government and other sectors have initiated various disaster management initiatives to address this issue. The disaster management plans that are formulated in the national level are adopted accordingly by the respective states and the districts based on various factors such as the types of disasters prevalent in the particular region. A brief and comprehensible review of disaster management in India and Kohima in particular is being discussed further so as to equip us with the know how's of the various plans and policies as well as to ignite the various potentialities of disaster management.

5.1. Disaster Management in India

India's disaster management policies are extensive and diverse, including a broad spectrum of both natural and man-made calamities. The policies are designed to improve the country's readiness, reduction, response, and restoration capacities. Below is a summary of the fundamental elements of India's disaster management policies:

5.1.1. Legal and Institutional framework

i. **The Disaster Management Act of 2005** establishes the legal structure for managing disasters in India. The National Disaster Management Authority (NDMA) was created at the national level, while State Disaster Management Authorities (SDMAs) were formed at the state level, and District Disaster Management Authorities (DDMAs) were set up at the district level.

ii. **The National Policy on Disaster Management (NPDM) was established in 2009.** This policy delineates the overarching goals, purpose, and specific aims for the management of disasters in India. The method stresses a proactive and comprehensive strategy that encompasses all stages of disaster management, including prevention, mitigation, readiness, response, and recovery.

5.1.2. National-Level Institutions and Plans

i. **The National Disaster Management Authority (NDMA)** is tasked with developing policies, strategies, and guidelines for the handling of disasters. It collaborates with many government departments and organizations to guarantee efficient execution of disaster management tasks.

ii. **The National Disaster Response Force (NDRF)** is a specialized force established to provide catastrophe response and assistance. It performs a crucial function in search, rescue, and rehabilitation activities in times of calamities.

iii. **The National Disaster Management Plan (NDMP)** is a comprehensive strategy that outlines specific measures for mitigating and handling disasters at the national, state, and district levels. The objective is to enhance India's ability to withstand catastrophes by minimizing risks and strengthening capacity to manage them.

5.1.3. The Institutional framework of Disaster Management in India

The Ministry of Home Affairs is the central agency responsible for coordinating all disaster management actions in the entire country. The Ministry of Water Resources, via the Central Water Commission, and the India Meteorological Department collaborate with the Central Relief Commissioner (CRC) to facilitate the coordination of help during natural disaster operations. The CRC relies on the predictions and warnings provided by these agencies to anticipate and respond to possible natural disasters.

Following is a list of ministries/departments/organizations that has primary and secondary disaster management responsibilities.

- India Meteorological Department
- Central Water Commission
- Ministry of Home Affairs
- Ministry of Defense
- Ministry of Finance
- Ministry of Rural Development
- Ministry of Urban Development
- Department of Communications
- Ministry of Health
- Ministry of Water Resources
- Ministry of Petroleum
- Department of Agriculture & Cooperation
- Department of Surface Transport
- Ministry of Social Justice
- Department of Women and Child Development
- Ministry of Environment and Forest

- Department of Food

- Ministry of Power

- Department of Civil Supplies

- Ministry of Railways

- Ministry of Information and Broadcasting

- Planning Commission

- Cabinet Secretariat

Furthermore, apart from the aforementioned organizations, many organizational entities collaborate in groups to effectively coordinate their activities in disaster management in India.

- **Crisis Management Group (CMG)**: The Crisis Management Group (CMG) is headed by the Central Relief Commissioner and consists of nodal officials from pertinent ministries and departments. The CMG evaluates and examines backup plans, organizes actions taken to prepare for and respond to catastrophes, and convenes regularly during emergencies to oversee relief activities.

- **National Crisis Management Committee (NCMC)**: The National Crisis Management Committee (NCMC) is headed by the Cabinet Secretary and comprises secretaries from all relevant ministries and agencies. It controls the CMG and assures prompt reaction actions. The Secretary of the Ministry of Home Affairs provides regular updates to the National Crisis Management Committee (NCMC) about all ongoing events.

Operational Centres - The Emergency Operations Centre, often known as the Control Room, operates 24/7 under the Ministry of Home Affairs to provide assistance to the CRC. The organization gathers and spreads information on natural disasters, collaborates with state governments, and engages with central ministries and agencies.

Planning and Funding:

-**Contingency Action Plan (CAP)**: The Contingency Action Plan (CAP) is a comprehensive national strategy designed to effectively manage natural disasters. It is regularly revised to enable swift and efficient relief operations. The document delineates the responsibilities of different ministries and agencies and defines certain centres within the administrative apparatus.

- **State Relief Manuals:** Each state has its own relief manuals or regulations, which establish the responsibilities of state officials in the administration of calamities. These instructions are regularly revised in response to experiences and evolving requirements.

- Funding Mechanisms: The Finance Commission conducts a comprehensive assessment of the policies and resources allocated for disaster assistance every five years. The Calamity Relief Fund (CRF) in each state is primarily financed by the federal government, which contributes 75% of the funds, while the state government provides the remaining 25%. If there are significant calamities, governments have the option to seek extra aid from the National Calamity Contingency Fund (NCCF).

State Level:

- State Governments: The primary responsibility for disaster response, relief, and rehabilitation lies with state governments. Departments of Relief & Rehabilitation manage these efforts at the state level.

- State Crisis Management Committee: Chaired by the Chief Secretary, this committee includes representatives from all relevant state and central government departments. It reviews response actions and issues necessary guidelines.

- Control Room: Established under the Relief Commissioner, this room monitors climate data and coordinates disaster response efforts across various agencies.

District Level:

- District Administration: The Collector/District Commissioner leads disaster management at the district level, preparing district plans, and overseeing relief efforts.

- District Level Coordination and Relief Committee: Headed by the Collector, this committee includes government and non-governmental agencies, and elected representatives. It ensures coordinated disaster preparedness and response.

- Local Coordination: The Collector maintains close contact with state governments, armed forces, central police organizations, and relevant central government departments to support district-level disaster management.

India's disaster management system is characterized by a multi-level, multi-agency strategy, which guarantees a well-coordinated and efficient disaster response and relief operations at the national, state, and district levels.

5.2. Disaster Management in Nagaland

Disaster Management in Nagaland is a comprehensive approach. Disaster management requires a holistic strategy that encompasses all facets of crisis response. The Nagaland State Disaster Management Authority (NSDMA) was established in January 2011 with assistance from the Government of India, United Nations Development Programme’s Disaster Risk Reduction Project (GoI-UNDP DRR Project). There were no personnel or officers stationed at NSDMA. With the assistance of GoI-UNDP, a State Project Officer was hired by UNDP and stationed in the NSDMA Secretariat to establish a dedicated institution for Disaster Management in the State. The Nagaland State Disaster Management Authority (NSDMA) was established with a full-time Secretary and other staff appointed on a contractual basis, with the backing of the Government of India and the United Nations Development Programme (UNDP).

The NSDMA secretariat is led by the Home Commissioner, who serves as the Chief Executive Officer. At the administrative level, there is a full-time Secretary. The Program and Establishment unit is led by State Project Officer, who is assisted by the Accounts Officer.

Also, four District Project Officers (DPOs) were hired at the District Disaster Management Authority level. These officers are assigned to DDMA Kohima, DDMA Mokokchung, DDMA Dimapur, and DDMA Peren. The recruitment was made possible with the help from the Government of India (GoI) and the United Nations Development Programme (UNDP). It is reported that there now exists a DDMA in each district of Nagaland.

The Nagaland Disaster Management Plan (NDMP) was released in 2012 prioritizing the use of indigenous resources (knowledge, manpower, and materials) to guarantee a more streamlined, cost-efficient, and prompt response to any calamity. Efficient disaster management entails the synchronization of many agencies, organizations, persons, and resources to collaborate with communities during times of emergencies. In order to effectively handle disasters in Nagaland, it is crucial to include the community via traditional representative entities like as the Councils and Tribal Hohos, since they have strong community links. Having access to information is crucial for effective planning and execution. The strategy for NDMP emphasizes the establishment of information repositories at both large-scale and small-scale administrative levels, with the aim of facilitating efficient networking and sharing of resources after a catastrophe. Every district is required to develop a strategy that takes into account its unique vulnerabilities to disasters, making use of local resources and expertise. The strategy should possess adaptability to effectively respond to emergency events, necessitating ongoing updates and enhancements.

According to the Nagaland State Disaster Management Plan (NDMP), it focuses on minimizing casualties, property damage, and disruptions to social and economic activity in the communities. It prioritizes the development of plans for execution before, during, and after a disaster occurs. During the Pre-Disaster Phase, the primary focus will be on implementing risk reduction, disaster preparation, and disaster mitigation activities. The primary objectives of Risk reduction initiatives include:

i. Implementing strategies to prevent human settlement in vulnerable regions.
ii. Creating and implementing technical measures to mitigate and eradicate natural hazards.
iii. Constructing structures that are resistant to hazards.
iv. Establishing a comprehensive preparation plan at all response levels to facilitate swift recovery from any catastrophic event.

Disaster preparation is the creation of a well-designed strategy to address potential disasters. This strategy involves assessing the requirements for emergency situations and determining the necessary resources to fulfil those requirements. The objective is to provide the local community and stakeholders with the necessary skills and resources to effectively address a catastrophe scenario.

Disaster preparedness measures include several aspects, including the following:

i. Capacity to effectively respond to and mitigate the impact of disasters. Efforts to construct or create at different degrees of reaction.
ii. Establishing and enhancing local mechanisms for responding to emergencies. Consequently, it is crucial to formulate response strategies that are tailored to the specific challenges and requirements at the village level. This necessitates the development of comprehensive plans that include each individual village council unit. This principle also extends to every Ward and Colony under the jurisdiction of the

Municipal and Town committees in terms of their preparedness and reaction to any potential calamity.

iii. Establishing efficient district-level response mechanisms. Each District will be required to create a District Plan within a certain timeframe.

iv. Compiling an inventory of current facilities and resources at every level of response. This will be seen in the District Plans.

v. Developing and implementing efficient alert systems that are easily recognizable and comprehensible to the local population.

vi. Conducting information and awareness campaigns via media, seminars, workshops, and developing educational curricula for academic institutions.

The Nagaland State Disaster Management Plan acknowledges the significance of integrating Disaster Mitigation Strategies within the State's Pre-Disaster Plan. Disaster mitigation is a process that aims to identify and address the specific risks that might lead to disasters. Its goal is to remove or minimize these hazards in the local environment in order to prevent or decrease their immediate impact. Disaster mitigation measures encompass:

i. Enforcing rigorous compliance with construction regulations and by-laws.

ii. Conducting surveys and evaluations of buildings and structures that exhibit structural weaknesses.

iii. Enhancing the resilience of infrastructure in vulnerable regions.

iv. Implementing micro-zonation at the district level to create tailored response strategies.

v. Engaging local people by integrating their Indigenous traditional knowledge to mitigate dangers and risks.

vi. Risk assessment and vulnerability assessments will be conducted at each District level by competent entities that have been recognized.

vii. To allocate resources towards research and development activities, as well as the transfer of technology that is suitable for the specific local context.

viii. Implementation of initiatives aimed at mitigating vulnerabilities in high-risk regions and among certain demographics within the interior districts of the State.

ix. Facilitating and establishing collaborations across local Governments, Community-Based groups (CBOs), Non-Governmental Organizations (NGOs), and Community groups to enhance and formulate mitigation measures tailored to the specific requirements at each level of response.

x. Enforcing land use regulations and ensuring secure placement of buildings and infrastructure.

xi. Including an assessment process in the Response plan that consists of regular surveys, regular reporting, and regular meetings to assess progress. This should be implemented at the District and State level to aid in reevaluating and scrutinizing the choices accessible to policymakers and the community.

The activities during the Post-Disaster Phase will primarily concentrate on the process of recovery. Recovery encompasses all forms of aid given to individuals and communities impacted by crises, with the aim of helping them regain a satisfactory and efficient level of functioning. Recovery activities may be categorized into short-term and long-term endeavors.

Short Term Recovery initiatives include

i. The restoration of essential services to the impacted region.

ii. Restoration of damaged infrastructure, residences, and structures.

iii. Evaluation of the impact on infrastructure, economic activities, and productivity.

iv. Offering specialized services to support people, families, and communities in the social, financial, and psychological domains.

Long-term recovery initiatives include:

i. Evaluation and enhancement of the impacted region.

ii. Assessment of the efficacy of the Disaster Management Plan.

iii. Assessing and revising the strategies for reducing the impact of the disaster on the impacted region.

The Nagaland State Disaster Management Plan is founded on the notion of community engagement and active participation. Implementing a participatory and collaborative approach, including the community and stakeholders in the preparation and execution of the Nagaland State Disaster Management Plan, would effectively eliminate risks and vulnerabilities, ensuring the successful implementation of the plan. During a crisis, communities and people will be motivated to become self-sufficient by raising awareness and equipping them with the necessary skills to handle calamities. In addition, it is crucial to include comprehensive workshops and seminars prior to a catastrophe, specifically targeting Tribal Hohos, community leaders, Gaonburas, and community organizations. These sessions should aim to foster a practical comprehension of their respective roles and duties in emergency or disaster scenarios.

5.2.1. Objectives of the Nagaland State Disaster Management Plan (NSDMP)

i. Identify and assess vulnerabilities: Evaluate the state's sensitivity to several types of natural and man-made disasters.
ii. Formulate prevention and mitigation measures to effectively address and minimize the impact of disasters.
iii. Define Stakeholder Roles: Establish explicit rules and standards for stakeholders.
iv. Enhance Capacities: Bolster the capabilities of government and volunteer organizations, as well as the community, to effectively react to disasters.
v. Implement a structured Management Information System (MIS) to serve as the basis for disaster response.
vi. Encourage the use of Indigenous Knowledge: Integrate the expertise and wisdom of local communities into programs aimed at preventing and mitigating disasters.
vii. Promote Awareness and Disseminate Information: Establish a repository of information to enhance public consciousness and disseminate knowledge on disasters.
viii. Integrate capacity building: Ensure that capacity building and skills development are essential components of the disaster management strategy.
ix. Secure Adequate Funding and Resources: Obtain a substantial amount of financial support and necessary resources to ensure the long-term viability and efficiency of the strategy.
x. Encourage community engagement throughout the process of organizing and executing activities to facilitate community participation.
xi. Strengthen policy by implementing legal sanctions: Improve disaster management policies by including suitable legislative measures.

5.2.2. State Response Plan

The State Response Plan provides guidelines for officials, agencies, and organizations to organize an initial response to disasters. It outlines responsibilities during emergencies, emphasizing more delegation of power to lower governance levels, like Village Councils and Wards, and financial devolution for emergency management. The plan also highlights the importance of capacity building for local personnel in search and rescue, first aid, and shelter management.

Roles and Responsibilities of State Response Plan includes the discharge of instructions by the

a. State Emergency Operations Centre (SEOC):

i. Activate fully upon receiving disaster information.
ii. Issue alerts and warnings.
iii. Send reports to National Emergency Operation Center (NEOC) and Ministry of Home Affairs (MHA).
iv. Arrange State Executive Committee SEC meetings and activate Emergency Support Function ESFs as needed.

b. State Disaster Management Authority (SDMA):

i. Convene meetings directed by the Chief Minister.
ii. Direct response measures.
iii. Decide on inter-state assistance.

c. State Executive Committee (SEC):

i. Convene meetings for assessment and directions.
ii. Coordinate response efforts.
iii. Requisition National Disaster Response Force NDRF or Armed Forces if necessary.
iv. Monitor and review situations regularly.

5.2.3. District Level Action:

According to the NSDMP, a sequence of action on disaster management should be followed in the district level as well and thus is as follows:

a. District Emergency Operations Centre (DEOC):

i. Activate upon receiving disaster information.
ii. Issue alerts and warnings.
iii. Send initial and daily situation reports.
iv. Maintain records and activate Emergency Support Functions (ESFs) if necessary.

b. District Disaster Management Authority (DDMA):

i. Assess situations and direct immediate response measures.
ii. Requisition assistance from higher authorities if needed.

iii. Coordinate with civil society and Non-Governmental Organizations (NGOs).
iv. Monitor and review the situation continuously.

5.2.4. First Response and Information Management

In disasters without early warnings, community members act as the first responders, supported by police, SDRFs, fire, and medical services. Accurate information dissemination through media is crucial, with regular briefings by authorized representatives.

5.2.5. International Assistance and Post-Operational Debriefing

Assistance requests escalate from local to state to central levels, and potentially international aid agencies. Post-operational debriefings assess response adequacy and recommend plan adjustments.

5.2.6. Relief Efforts

State governments are responsible for providing relief to disaster victims, ensuring safety, security, and well-being through food, water, shelter, clothing, and medical care. Minimum standards of relief are set by NDMA and SDMAs.

5.2.7. Mechanism for International Assistance

If local resources are insufficient, requests for assistance escalate from local to district to state levels, and potentially to the central government and international aid agencies.

In conclusion, the disaster management plan for Nagaland is a comprehensive and multi-tiered strategy that prioritizes the use of local resources, community participation, ongoing planning and updating, and a coordinated response system at different administrative levels.

5.3. Disaster Management in Kohima

The disaster management strategies of Kohima, the capital of Nagaland, India, are in accordance with both national and state-level frameworks. These strategies are designed to mitigate a range of catastrophes, including as seismic events, avalanches, and inundations, which are prevalent in the area owing to its geographic and climatic characteristics. Below is a summary of the current policies and frameworks.

5.3.1 National Policies and Frameworks

As discussed in the above sections (5.1 and 5.2), the following policies and frameworks both in national and state level plays a major role in the policies and laws of disaster management in the district level of Kohima and thus is important to be reviewed.

i. **The National Disaster Management Act, 2005** establishes the legislative structure for managing disasters in India. The National Disaster Management Authority (NDMA) was founded with the responsibility of formulating policies, strategies, and guidelines for the management of disasters.

ii. **The National Policy on Disaster Management (NPDM) of 2009** provides a comprehensive framework for disaster management in India. It sets out the vision, purpose, and goals, highlighting the need of a holistic approach that encompasses prevention, mitigation, preparation, response, and recovery.

iii. **The National Disaster Management Plan (NDMP)** provides a comprehensive strategy for decreasing the impact of disasters and managing them effectively at the national, state, and district levels. Its goal is to enhance the country's ability to withstand disasters by minimizing vulnerabilities and strengthening capacity.

5.3.2. State-Level Policies and Frameworks

i. **The Nagaland State Disaster Management Authority (NSDMA)** is a government body that has been established in accordance with the Disaster Management Act of 2005. This act requires every state to have its own disaster management authority. The NSDMA is tasked with the implementation of disaster management policies and strategies in Nagaland. It works in collaboration with different ministries and organizations to provide efficient preparation and response to disasters.

ii. **The Nagaland State Disaster Management Plan (NSDMP)** is a comprehensive strategy that explains the state's approach to disaster management. It includes activities such as risk assessment, allocation of resources, development of capabilities, and coordination among different stakeholders.

iii. **District Disaster Management Authorities (DDMAs)** are accountable for strategizing, organizing, and executing disaster management initiatives at the district level. Their primary objective is to ensure that these efforts are customized to address the distinct requirements and susceptibilities of the local populace.

The Nagaland State Disaster Management Authority (NSDMA), which operates under the Home Department of the Government of Nagaland, requires the development of district and subsidiary disaster management plans. The District Disaster Management Committee (DDMC), acting as an advisory entity, formulates these plans in collaboration with pertinent line departments, community-based groups, NGOs, and other stakeholders. The District Disaster Preparedness and Response Plan integrates data from many official and informal sources to efficiently tackle issues in the event of any calamity. The Deputy Commissioner, along with other government authorities, is tasked with the responsibility of overseeing the management of risks and catastrophes that impact the district. This is done in collaboration with NSDMA, the Home Commissioner, and other relevant public and private institutions. The DDMA operates under the wider framework created by the NDMA and SDMA of Nagaland.

5.3.3. District Disaster Management Plan (DDMP):

The District Disaster Management Plan (DDMP) for Kohima district is an all-encompassing framework specifically developed to tackle disaster management in the district, in accordance with national and state legislation. The following is a summary of the main elements and tactics included in the plan:

5.3.3.1. Objectives:

Prevention and Mitigation: Minimize the likelihood of disasters by taking proactive measures and reducing possible consequences.

i. Preparedness: Improve the district's readiness by strengthening its capacity, providing training, and increasing public awareness.

ii. Response: Establish a comprehensive and well-coordinated response system to effectively mitigate the impact of catastrophes and reduce casualties and property damage.

iii. Expedite the process of recovery and restoration for communities impacted by disasters.

5.3.3.2. The framework of the organization:

i. The District Disaster Management Authority (DDMA) is headed by the Deputy Commissioner of Kohima and is tasked with the planning, coordination, and execution of disaster management initiatives.
ii. The District Emergency Operations Centre (DEOC) serves as the central command center during emergencies, facilitating efficient communication and coordination among several agencies.

5.3.3.3. Hazard, Vulnerability, and Risk Assessment:

i. The plan provides an identification of significant risks in Kohima, including earthquakes, landslides, floods, fires, and hazards caused by human activities.
ii. Vulnerability Analysis: Thorough evaluation of places prone to harm, essential infrastructure, and people who are susceptible to danger.
iii. Risk Mapping: Development of risk maps that identify areas with a high risk of catastrophes and key infrastructure that is vulnerable to such events.

5.3.3.4. Precautionary Measures:

i. Capacity Building: Consistent training initiatives for government officials, community leaders, and volunteers focused on enhancing their skills and knowledge in disaster management.
ii. Public Awareness: Initiatives aimed at enlightening the general public about catastrophe preparation, safety protocols, and evacuation strategies.
iii. Implementation of early warning systems to promptly notify and inform individuals of probable calamities.

5.3.3.5 Strategies for reducing or minimizing the impact of a problem or risk:

i. Infrastructure Resilience: Implementation of stringent construction rules and strategic land-use planning to guarantee that buildings are capable of enduring and withstanding catastrophic events.
ii. Environmental Conservation: Efforts aimed at preventing deforestation, promoting soil conservation, and effectively managing water resources in order to mitigate the risks of disasters.
iii. Enhancing the resilience and durability of vital infrastructure such as hospitals, schools, and bridges by retrofitting and strengthening measures.

5.3.3.6 Response mechanisms:

i. Emergency Response Teams (ERTs) are created as specialized units that undergo training in search and rescue operations, medical assistance, and logistical support.
ii. Development of comprehensive evacuation plans, including the creation of detailed strategies for routes, shelters, and transportation specifically designed to assist vulnerable groups.
iii. Resource Inventory: The act of maintaining a comprehensive list of vital resources, such as food, water, medical supplies, and equipment.

5.3.3.7. Recovery and rehabilitation:

i. Damage and Needs Assessment: Swift evaluations conducted to ascertain the magnitude of harm and urgent requirements in the aftermath of a calamity.
ii. Reconstruction Plans: Approaches for reconstructing and revitalizing vital services in a way that is both environmentally friendly and able to withstand future challenges.
iii. Psychosocial Support: Offering mental health treatments and assistance to people and communities impacted by the situation.

5.3.3.8. Coordination and communication:

i. Inter-Agency collaboration: Establishing efficient mechanisms to facilitate collaboration across government agencies, non-governmental organizations (NGOs), and community groups throughout all stages of crisis management.
ii. Public Communication: The use of various communication channels, such as radio, social media, and public announcements, to provide information during catastrophes.

5.3.3.9. Surveillance and assessment:

i. Regular Drills and Exercises: Implementing simulated drills and exercises to evaluate the efficiency of the disaster response strategies.
ii. Evaluate and Revise: Regularly reviewing and upgrading the DDMP to integrate new knowledge gained, tackle growing risks, and enhance disaster management techniques.

The DDMP, for Kohima district intends to improve disaster resilience, response effectiveness, and recovery speed by adopting comprehensive strategies and measures. This will protect the lives and livelihoods of the area's population.

5.4. Non-Governmental Organizations

There exists a good number of communities and organizations that plays a crucial role in times of disaster. In the case of Kohima in particular and Nagaland in general, with the existence of various Church organizations, Youth organizations, Village organizations, Students organizations and Tribal organizations including various non-profit organizations, are highly equipped in terms community engagement factor as stated by the NSDMP. However, the level of community awareness and community engagement in disaster management is seen to be at a seemingly low radar. It is notable that such organizations are not as actively involved in disaster management as are involved in various political aspects. It is important to note that while every socio-economic and political aspect is important, a disaster stricken and disaster vulnerable region will never be able to function to its highest capability given the drawbacks disaster brings with it. Therefore, community engagement stands at the highest requirement in the scenario of an effective disaster management. However, some of the few notable NGO's and non-profit organizations in Kohima that are worth mentioning are as follows:

i. **The Nagaland Voluntary Health Association (NVHA**):
It is a nonprofit organization founded in 1994. Its key focus areas are education, health, gender, child and youth development, and livelihoods. The main headquarters of the organization is located in Kohima, Nagaland. NVHA offers medical assistance and emergency healthcare services in times of catastrophes, in addition to conducting community health education and awareness initiatives.

ii. **The Eleutheros Christian Society**, popularly referred to as 'ECS', is a community project spanning numerous districts in Nagaland, one of India's most underdeveloped areas. Situated inland and sharing a border with Myanmar to the east, the project was initiated in 1993 as a reaction to the issue of drug misuse, which was further exacerbated by the high incidence of HIV among the population of individuals who inject drugs. Their major objective was to improve the well-being of drug users. However, the attempts to assist them led them to also focus on the broader community and tackle the underlying societal issues that contribute to these problems. Currently, ECS focuses on addressing several aspects of rural development, including health, education, water and sanitation, livelihoods, and environmental concerns.

iii. **The Indian Red Cross** is a volunteer humanitarian organization established in 1920 under the Indian Red Cross Society Act and incorporated under Parliament Act with an extensive network of more than 1200 branches throughout the nation. It offers assistance during times of catastrophes and crises and works to improve the health and well-being of disadvantaged individuals and communities. It is a prominent member of the biggest autonomous humanitarian organization globally, the International Red Cross & Red Crescent Movement. The movement has three primary constituents: the International Committee of the Red Cross (ICRC), National Societies, and the International Federation of Red Cross and Red Crescent Societies. The primary objective of the Indian Red Cross is to inspire, motivate, and undertake various humanitarian endeavors in order to lessen and perhaps prevent human suffering. By doing so, it aims to create a more favorable environment for peace.

iv. **Lions club, Dimapur**: This club was founded in 1917 based in USA and went international in 1920. Their primary reputation is in the efforts to combat blindness, but also actively engage in many community initiatives such as environmental conservation, alleviating hunger, and providing assistance to elders and those with disabilities. The Foundation and Lions are collaborating to assist communities affected by natural disasters. Efforts include addressing urgent necessities such as food, water, clothes, and medical supplies, as well as contributing to long-term restoration.

Few other NGOs worth mentioning are the Royal Club Kohima, the Classic Club Kohima, and the Rotary club Kohima all of which plays a whole range of roles in creating environmental awareness, providing education, raising orphans, health care facilities and volunteering works in hospitals and the likes where human service is a necessity.

5.5. Community awareness level on geomorphic hazards and risks in Kohima district

In order to assess the level of community awareness about geomorphic hazard, disaster, their risk, and mitigation measures, a detailed social survey has been conducted using sample survey method (Lynn (2002,2008; Groves, 2004). Sample survey method is an exercise that deals with collecting standardised data from a sample of study unit designed to represent larger population of concerning unit. Following this method, smallest administrative unit, that is, ‘ward’ either in village or city/town has been considered here to collect sample data by interviewing two families in each ward of a village and four families in each ward of a city or town. So, the sample size varies according to the number of wards of village, city and town. Exclusively designed questionnaires in collaboration with the local authorities (Patwari, Gram Pradhan etc.) was used to conduct interview surveys. All members above 15-year age of selected sample family have been interviewed with the help of questionnaire.

The results of the exercise revealed that in general the awareness level of Kohima district is low on geomorphic hazards and their risks. Maximum proportion i.e., 58% of total population has low to very low awareness level, 26% population has satisfactory awareness level while only 17% population has good awareness level particularly in Kohima city zone (Table 5.1). The awareness level varies greatly from very poor to good across the district under its six administrative divisions in order of social, educational, cultural, demographical and economical background (Figure 5.1). Out of total six divisions of the district, Kohima Sadar has good awareness level on geomorphic hazards with a representation of 48% of population of the subdivision. Kezocha and Jakhama sub division have satisfactory level of awareness with representation of 37% and 46% population of the respective subdivisions. Chiephobozou and Sechu Zubza sub division stands at poor level of awareness with representation of 42% and 39% population of respective sub divisions whereas Botsa sub division was found at a very poor level of awareness on geomorphic hazards and their risks with representation of 55% population of the subdivision (Table 5.1).

Table 5.1: Community awareness level on geomorphic hazards in Kohima district, Nagaland

Circles	**Awareness levels (% of total population)**				
	Very poor	**Poor**	**Satisfactory**	**Good**	**Average**
Chiephobozou	31	42	18	9	Poor
Botsa	55	29	10	6	Very poor
Kezocha	28	18	37	17	Satisfactory
Jakhama	17	26	46	11	Satisfactory
Kohima sadar	13	18	21	48	Good
Sechu Zubza	32	39	21	8	Poor
Average (Kohima)	**28**	**30**	**26**	**17**	**Poor**

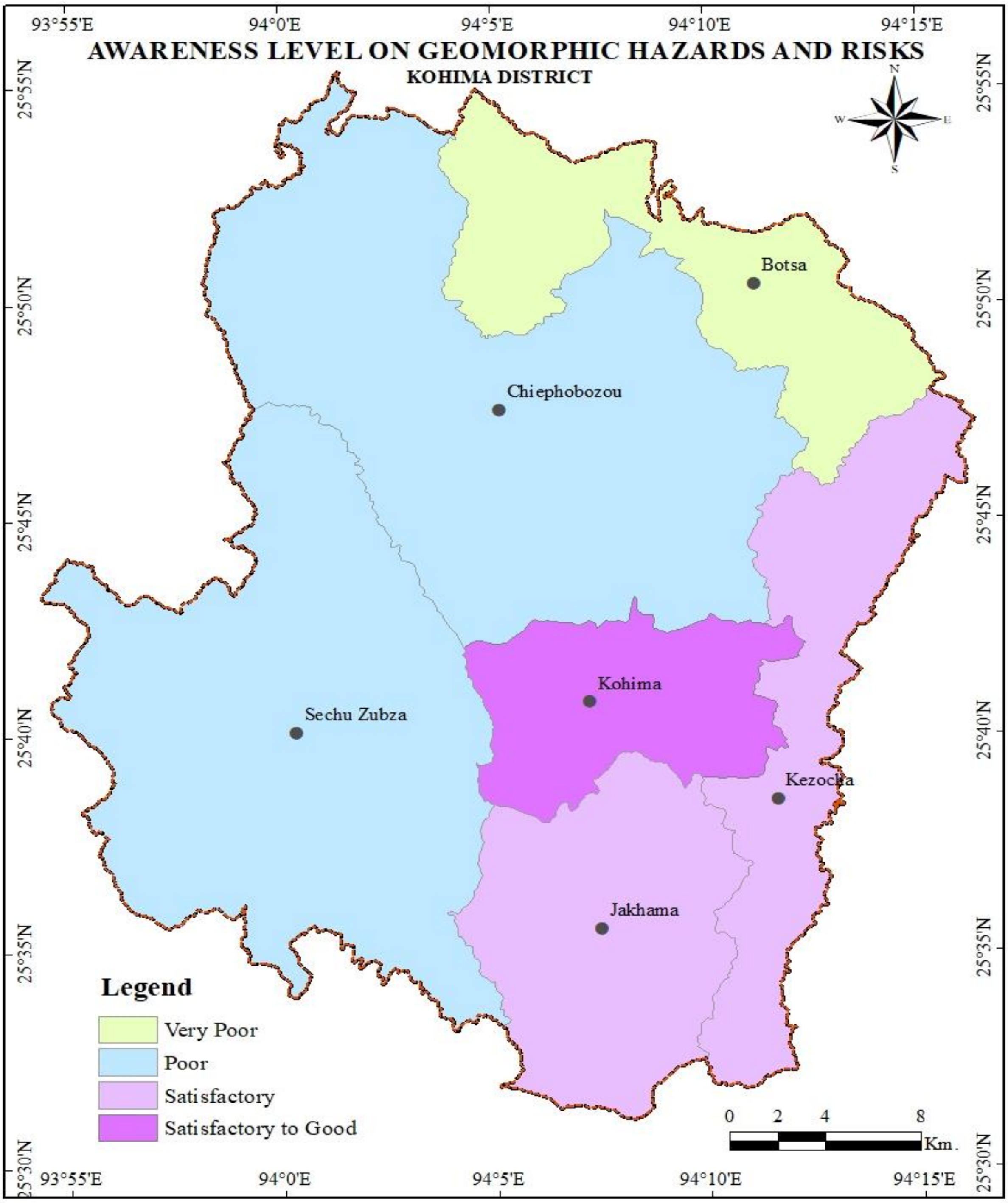


Figure 5.1: Community awareness level on geomorphic hazards in Kohima district

5.6. Disaster management problems in Kohima:

i. **Physiographical vulnerability:**

Kohima district as explained extensively in the preceding chapters is an extremely unstable region owing to its steep slopes and hilly terrain and its ever encompassing land use change over the years due to heavy developmental and infrastructural activities such as deforestation, road cutting, widening of settlement area have increased its vulnerability to various types of hazards which were focused mainly on geomorphic hazards- landslide, soil erosion, flash floods and earthquake in this research. Earthquake does not have it base on land use as it is solely dependent on the tectonic activity that takes place within the earth's surface. However, the intensity of its impact gradually increases on the basis of the manner in which land is being used. The disastrous effect of landslide, soil erosion and flash floods in Kohima is first subjected to the topographic vulnerability of the region and secondly to the increasing detrimental activities of human.

Figure 5.2: Disaster Management problems in Kohima

ii. **Infrastructure limitations:**

Kohima is faced with infrastructure limitations mostly in the case of good road network as the region being steep and hilly also, with the frequent occurrences of landslides along high ways, such as that of NH 29 extending from Zubza to the southernmost part of Kohima district in Khuzama village which connects the district as well as the state with the state of Manipur, transportation is affected and thus delay in deliverance of emergency services. There is also poor communication systems and power outage is a very common phenomena in time of rain and thunderstorms causing a barrier in the smooth functioning of management. There is also poor urban planning and lack of compliance to building codes either due to insufficient knowledge or dissemination of awareness or simply ignorance of the population.

iii. **Interagency coordination:**

Interagency communication problems also rises when there is varying communication protocols and systems, leading to misunderstandings and delays. Also, there are cases of information silos where agencies may hoard information instead of sharing it, leading to incomplete situational awareness. This can result in duplicated efforts or gaps in response. Overlapping responsibilities and authority disputes, inconsistent SOPs and training disparities are also some of the reasons of poor interagency coordination in disaster management in Kohima.

iv. **Delay in relief and rescue:**

This owes its reasons to the various factors of poor transportation, the topographic vulnerability, poor coordination and lack of training. While it is commendable that the NSDMA and the DDMA are making efforts in the various aspects of disaster management such as organizing trainings and workshops, providing relief and care, there is ample room for improvement with greater support from the government as well as the public in general.

v. **Poor training:**

Poor training can be subjected to the type of training given and the audience it is serving. The NSDMA is reported to organize trainings and courses to schools in the case of emergency disaster evacuation, there is also curriculums in educating on disaster management. However, the target group should not only be focused on the students and institutions but also to the general public. The illiterate and the older group of population who are devoid of any kind of training or education unless one reaches out. Therefore, much effort should be given on the training basing on the prospects of it as well as targeting the entirety of population as disaster knows no age, race or gender.

vi. **No psychological treatment:**

There is a lack of psychological treatment in the plans and policies of disaster management and is also hesitantly accepted by the community due to the ever-existing stigma on mental health. Psychological treatment of victims is an effective approach in making disaster management more effective and elaborate in the sense that victims who have survived disasters and have had proper mental treatment will be better equipped to share knowledge as well as carry out more effective practices of disaster management.

vii. **Faulty developmental schemes:**

Detrimental developmental schemes prevail everywhere and Kohima is also one that falls under the threat of the consequences of such schemes. Developments in road widening, deforestation for extension of settlement areas and more are not backed up by properly informed and girded with proper scientific and technological knowledge making the already topographically vulnerable Kohima more exposed to the disastrous impact such activities have. We have seen news reports on deaths and casualties caused as a result of such unscientific and ignorant practices of rock cutting along the NH 29 road.

viii. **Ignorance of local needs:**

This factor also serves as a problem as local needs are voiced out by local people who are well aware of traditional and cultural knowledge as well as the nature of one's own area which are ignored most of the times thus causing a communication gap and eroding trust between the local bodies and disaster management agencies of the government giving way to poor management of disaster and poor coordination.

ix. **Poor technology:**

Technological advancement on the field of disaster management in Kohima is slow in pace and requires upgradation. While traditional methods can be effective in management of disasters such as bamboo meshing on landslide affected areas, modern technology will not only help but enhance and replace it with better tools of management. GIS, early warning tools and communication systems are some of the various technologies the govt. has to invest at large.

x. **Misutilization of relief:**

This is not a new problem in a management system. Reliefs and funds that are brought in to the district does not reach the targeted group in the full amount or sometimes it does not reach at all. This is all due to the corruption and fault play of people in the system with ignorant and selfish motives which has to be strictly checked, penalized and corrected.

xi. **Poor rehabilitation efforts:**

Poor rehabilitation efforts in Kohima are due to a lot of reasons such as poor infrastructure, poor transportation, poor communication and poor coordination.

xii. **Community engagement:**

Lack of Community engagement is one of the major setbacks in the context of disaster management. The authority tries to take matter into its own hands without handing out proper information and thus at the end the victim becomes the lone sufferer in most cases. Enough relief funds are not handed out, proper information and awareness are not handed out by the experts in the authority and thus results in lack of communication between the community and the government creating more loopholes in the already existing disaster management problem. Though the NSDMP has given ample emphasis on community engagement in disaster management, there has been very little growth in it.

xiii. **Climate change:**

Climate change is the one factor that is of utmost concern at the moment. Kohima is no longer immune to the negative impacts of climate change. It has been seeing a rapid rise in temperature, rise in number of drought days, rise in extreme rainfall with lowering rainy days, mounting climatic zones from temperate to humid tropical zones thus resulting into more disasters every year.

In conclusion, one can say that means and ways for disaster management is available at large, however, the task of applying all knowledge to action seems to be lacking.

References

Bansal, R.C. & Mathur, H.N. (1976). Landslides- the nightmare of roads. *Soil Conservation Digest, 4(1)*

Government of India (2022-23). Annual Report, *National Disaster Management Authority*

Government of India (2021-22). Annual Report, *National Disaster Management Authority*

Government of India (2020-21). Annual Report, *National Disaster Management Authority*

Government of India (2019-2020). Annual Report, *National Disaster Management Authority*

Government of India (2018-19). Annual Report, *National Disaster Management Authority*

Government of India, Contingency action Plan for Natural calamities, *unpublished report of Ministry of Agriculture, Department of Agriculture and Cooperation, N.D.M. Division*, New Delhi

Government of India. (2005). Disaster Management Act

Government of India (n.d.). Disaster Management in India, *Ministry of Home Affairs*

Government of India (2019): National Disaster Management Plan

Government of India (2009). National policy on Disaster Management, *Ministry of Home Affairs,*

Government of India (2007). National Disaster Management Guidelines, Preparation of state Disaster Management Plans, *National Disaster Management Authority*

Government of India (2010). National Disaster Management Guidelines On Ensuring Disaster Resilient Construction of Buildings and Infrastructure financed through Banks and Other Lending Institution, *National Disaster Management Authority*

Government of India (2012). UNDP Disaster Risk Management Programme 2002-2009: Evaluation and Review of Lessons

Government of Nagaland (2019). District Disaster Management Plan Kohima

Government of Nagaland. (2012). Nagaland State Disaster Management Plan, *Nagaland State Disaster Management Authority, Home Department*

Government of Nagaland (2007): Nagaland State Disaster Management Rules, *Nagaland State Disaster Management Authority, Home Department*

Government of Nagaland. (n.d.). Standard Operating Procedure, *Nagaland State Disaster Management Authority, Home Department*

Groves, Robert & Fowler, Floyd & Couper, Mick & Lepkowski, James & Singer, Eleanor & Tourangeau, Roger. (2004). Survey Methodology. 561

International Committee of the Red Cross: https://www.icrc.org/en

Lynn P (2008) The problem of nonresponse. In: deLeeuw E, Hox J, Dillman D (eds) The international handbook of survey methodology. Lawrence Erlbaum Associates, Mahwah, NJ, pp 35–55.

Lynn P (2002) Sampling in human studies. In: Greenfield T (ed) Research methods for postgraduates, 2nd edn. Arnold, London, pp 195–202.

Prakash, I. (1994). Disaster Management, Rasthra Prahari Prakashan, New Delhi

Satendra. (2001a). Disaster And Development; Silver Jubilee Issue of Employment news, Publication Division, *Ministry of Information and Broadcasting*, New Delhi

Satendra. (2001b). Dealing with Disaster, Dow to Earth, vol 9 No. 23, *Centre for Science and Environment*, New Delhi

Satendra. (2003). Disaster management in the Hills. *Concept Publishing Company*, New Delhi

Sally H. Potter, Peter V. Kreft, Petar Milojev, Chris Noble, Burrell Montz, Amandine Dhellemmes, Richard J. Woods, Sarah Gauden-Ing, (2018). The influence of impact-based severe weather warnings on risk perceptions and intended protective actions, *International Journal of Disaster Risk Reduction*, Volume 30, Part A, Pages 34-43, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2018.03.031.

United nations' Office for Disaster Risk Reduction (UNDRR): United Nations International Strategy for Disaster Reduction (UNISDR) strategic framework 2016-2021

Valdiya, K.S. (2001). Dynamic Himalaya. Jawaharlal Nehru Centre for Advanced Scientific Research. Universities Press (India) Limited

Valdiya, K.S. (2004). Coping with Natural hazards: Indian Context. (Ed.). the National Academy of Sciences, Allahabad

Strategies for Mitigation and Management of Geomorphological Hazards in Kohima District

Hazards may be unavoidable in some instances, but their impact may be mitigated to reduce severity and risk. This may be accomplished by promptly taking action to deal with dangers. These strategies mitigate the severity and magnitude of disasters by altering the patterns of occurrences and dispersing the detrimental consequences. Due to the inherent characteristics of geohazards and the geodynamic conditions on the Indian subcontinent, it is impractical to expect the prevention of geological occurrences that lead to disasters. Individuals must have the ability to coexist with natural dangers in specific regions and develop strategies to effectively manage the negative consequences that arise from them. Communities that are susceptible to dangers must possess the ability to endure the pressures of hazardous occurrences and maintain their functionality. This necessitates the placement or relocation of all life support systems in areas that are not susceptible to damage, and the design of key facilities to ensure their uninterrupted operation in the face of landslides, floods, storms, earthquakes, and other such events. This situation necessitates a change in approach from opposing to adapting. To enable communities to effectively address hazards, two key measures are required: i) Ensuring that hills are protected by vegetation to allow for proper absorption of rainwater, thereby reducing the risk of floods in floodplains and preventing slope failures. ii) Allowing floodplains to develop wetlands that can accommodate floodwaters. These metrics indicate a proactive strategy of foresight rather than a reactive one. It is crucial to reinforce all structures and infrastructure via the implementation of: i) building codes, ii) engineering designs, and iii) construction techniques (Valdiya, 2004). Another potential course of action is to permanently or temporarily evacuate the region that is susceptible or under attack. In India, specifically in Kohima, the only viable choice is to depart temporarily due to the scarcity of available land for relocation. The strain exerted by the fast-expanding population is the cause of the habitation and use of areas that are prone to hazards. Within mountainous regions, individuals are limited in their ability to traverse the steep, densely wooded inclines. The high population density in urban areas also exposes individuals to the perils of pollution. Individuals living in challenging conditions have no alternative but to engage in hazard-preparedness initiatives inside areas that are known to be prone to hazards. In other words, it is crucial to develop strategies for dealing with catastrophes by considering geological-geomorphological assessments, the physical characteristics, scale and occurrence patterns of previous events, and the current geophysical and terrain transformations.

6.1. Strategy for seismic hazard management

i. **Seismic zoning map**: A seismic hazard zoning map illustrates different belts or areas that are susceptible to seismic changes caused by earthquakes. The zoning of sensitive regions is determined by three factors: the geographical positioning of previous and current earthquake epicenters, the projected intensity of ground shaking, and the assessed potential hazards to human settlements, utility structures, communication systems, and supply lines.

To get more precise information on the seismic activity in a designated susceptible region, it is recommended to conduct a thorough microzonation study (Bhandari, 2002). This comprises the process of systematically mapping the many risks in metropolitan areas, taking into account factors like as soil types, site amplification, monitoring the water table, spring discharges, and the characteristics of earthquake swarms.

ii. **Seismic risk assessment**: Seismic risk refers to the potential losses that can happen in an area as a result of earthquakes. It is evaluated by considering three factors: a) the estimation of seismic hazard, which involves assessing the expected intensity of ground shaking, b) the level of seismic exposure, and c) the size of the population, infrastructure, and economy that are at risk from the seismic hazard.

Gathering and analysing relevant information to determine the location of potential earthquakes and estimate the probable magnitude of their impact is a crucial step in conducting a seismic risk assessment. To do this, it will be necessary to monitor physical changes such as ground surface swelling, land subsidence or sinking, and tilting of natural and man-made structures on slopes. It is necessary to monitor geophysical changes such as water table fluctuations, changes in spring discharges, increased radon gas emissions, heightened microseismic activity, variations in electrical resistivity, and changes in gravity values (Valdiya, 2004).

Although it is not feasible to forecast the exact timing, location, and magnitude of an earthquake (despite a few rare cases of accurate predictions), it is possible to identify regions that are likely to have earthquakes in the future. This may be achieved by a meticulous examination of the physical and geophysical parameters mentioned in the previous paragraph.

iii. Seismic risk mitigation: The strategies for addressing the issue include: a. increasing public awareness and providing training, b. implementing land use control measures, c. enforcing building regulations, d. retrofitting dangerous structures, and e. preparing financial aid and incentives.

The most essential steps may be ascribed to engineering and structural measures paired with suitable non-structural measures for decreasing damage and suffering. Although there are a multitude of measures that can be taken to mitigate earthquakes, the most important measures are those that are in place. Additionally, it includes legislative actions for the purpose of governing land use and urban planning. There is an urgent need for the formation of standards for new constructions as well as codes for retrofitting existing structures. The purpose of these codes is to avoid or at the very least drastically reduce the construction of buildings and infrastructures in environments that are hazardous. It is the responsibility of the federal government, state governments, and local organizations to guarantee that all structures created with public funding in locations that are prone to hazards adopt construction methods that are resistant to natural disasters. As a result of the current economic climate and the widespread poverty among the population, it is not feasible to either completely rebuild them or adapt themselves. However, there are several public and private structures, as well as community buildings, that should be renovated if they are deemed to be dangerous. These buildings include schools, dispensaries, hospitals, government offices, and other similar establishments. People would be able to use them as a model for upgrading their own houses as they would serve as an example. There is therefore a need for special budget provisions, making the general public aware of the upgrading of their residential buildings or those that are rented out to others by providing subsidies, reduced insurance premia, and other similar measures, and making the retrofitting of unsafe buildings and structures obligatory for a variety of public and private sector undertakings and businesses. Moreover, there must be a deterrent for not implementing strengthening measures, such as a reduction in compensation or the elimination of pay altogether for damage to buildings that have not been upgraded. It should be made mandatory to follow all relevant guidelines, where a certificate from a qualified structural engineer along with the complete structural drawings and design calculations should be submitted at the time of application for permission for construction of a building from the authority. This is because retrofitting of almost every structure, house, or building will be expensive, and as a result, it may be economically feasible to prioritize the structures or buildings that require retrofitting. In the event that any technical defect that puts the safety of the construction in jeopardy is found at a later time, the passing authority need to be held accountable for criminal negligence. Not only the owner/builder, but also the architect and the structural engineer are required to sign each and every certificate.

6.2. Strategy for Landslide Hazard Management

i. Landslide hazard mapping:

Both the process of planning for development and managing landslide disasters necessitate the use of hazard zonation maps. These maps are essential for projecting potential damage scenarios and conducting accurate risk assessments. The process of creating a landslide hazard map involves several important processes, as outlined by Valdiya (2004). These steps include:

a. The examination involves the study of geology, hydrology, seismotectonics, and land use of the area.

b. Analyzing the land management methods of the area.

c. Investigating and mapping the causal elements that influence instability in a specific geological context.

d. Identifying the most significant causal elements and then creating detailed maps.

e. comprehensive examination of the existing factor maps in conjunction with other relevant information, with the aim of identifying connections between the causal factors.

f. Generating a cartographic representation of a real landslide occurrence in the vicinity

g. Estimating the degrees of instability using the established criterion.

h. Integration of factor maps to generate a landslide hazard map on a GIS platform.

i. The process of validating the field by comparing it with an existing landslide map and adjusting the inferred hazard map to meet the agreed certification limit.

Understanding the magnitude of hazards is essential for individuals while constructing buildings, utility structures, roads, bridges, canals, dams, and other infrastructure.

ii. Landslide risk assessment:

The procedure of landslide risk assessment primarily involves the creation of a landslide hazard zonation map. The map depicting the condition of the natural environment on areas affected by previous landslides and areas with a high likelihood of landslides is typically regarded as the most crucial mapping. When assessing the probability and vulnerability of an area to landslide hazard, it is important to consider both intrinsic and extrinsic factors. Intrinsic factors include slope attribute, slope aspect, relative relief, bedrock geology, surface deposits, folding, faulting, and shear zone discontinuity. Extrinsic factors include rainfall, land use, land management, and construction activity. These factors should be carefully examined to determine the likelihood and susceptibility of an area to landslides. Utilizing GIS and remote sensing is crucial for achieving precision and effectiveness. Implementing landslide hazard prediction is a crucial innovation for enhancing capability in managing landslide hazards. The initial fundamental stage in predicting landslides is to conduct customized geotechnical research that takes into account the specific scenario, while also considering the slope's historical history and overall macro geomorphology. The second phase involves identifying the causal elements and gaining a comprehensive knowledge of how they interact across time. The third phase involves monitoring changes in pore water pressure, measuring displacements and displacement rates at crucial places, and defining the correlations between these variables. At this point, more studies and instruments may need to be utilized to gather more information and understand the process of the sliding mechanism. To achieve this goal, it is advantageous to utilize modelling techniques to forecast the parameters being measured. This will allow for a comparison to be made between the predictions and the actual observations in the field.

iii. Landslide risk mitigation

Hazard zoning maps and instrumental monitoring assessments of landslide causative elements serve as crucial foundations for designing a disaster management program. Landslides typically occur as a result of either heavy rainfall or seismic activity. Kohima has frequented and intense monsoonal rainfall, plus it is located in seismic zone V, making landslides unavoidable. Although both rainfall and seismic movements contribute to landslides, rainfall has a greater impact in causing quick and destructive landslides. Seismic movements, on the other hand, result in long-term displacement of rocks and are typically initiated by strong monsoonal downpours. Hence, water is the primary factor responsible for triggering or intensifying collective activity. Therefore, it is imperative to prevent water from infiltrating regions where the slope has become unstable. Landslide mitigation work may be categorized into two main types: control work and restraint work.

The control effort includes altering natural factors such as topography, geology, groundwater, and other elements that indirectly influence the movement of landslides. Restraint work include the construction of various structures, including surface and subsurface drainage systems, excavation in unstable areas, and the erection of buttress walls, piles, anchors, and retaining walls.

The rehabilitation of populations in vulnerable places is inevitable and frequently leads to conflicts between government officials and the affected individuals. Convincing people of the potential hazards of landslides and the associated economic, social, and psychological issues is a challenging task. Furthermore, the financial assistance provided by the government frequently falls short, and the proposed alternative options are frequently difficult. The people's reluctance to depart from the location where their family has resided for centuries is a significant limitation. Collectively, these factors hinder the recovery process (Thigale, 1995).

Afforestation is widely recognized as a very successful and environmentally benign method of management (Gupta, 1979; Valdiya, 1987; Sung-Hwan Kim et al, 1997).

Awareness programs are crucial in dispelling myths about hazards by highlighting the role of humans as the intruders, accelerators, and catalysts in commencing these dangers. The effectiveness of the awareness program, however, relies on the level of commitment and attention demonstrated by the individuals and organizations engaged in the initiative.

It is noteworthy that the tactics and approaches utilized for managing landslide hazards can also be applied to managing soil erosion hazards, since landslides are integrally linked to the processes involved in soil movement and erosion.

6.3. Strategy for Flash floods Hazard Management

i. Flash floods hazard mapping

The development of a flash flood hazard map for a mountainous location like Kohima relies on several key aspects, including slope, river run-off, drainage density, geomorphology, and geology of the area. It also relies on the quantity of precipitation the area gets. Consequently, all of these aspects are thoroughly examined and analyzed in order to create a map that accurately depicts the level of severity and susceptibility of the region to flash floods. Flash floods are often highly damaging (Starkel, 1972). Floods occur when the volume of water flowing in a river surpasses the maximum amount that the river channel can hold within its boundaries, typically during periods of intense rainfall or cloudbursts. The utilization of GIS and remote sensing methodologies has demonstrated significant efficacy in the fields of flash flood danger mapping and river discharge monitoring.

ii. Flash flood risk assessment:

The occurrence of flash floods in Kohima can be attributed to several factors, including a. Intense and prolonged precipitation, b. Accumulation of sediment in the riverbed leading to aggradation, and c. Decreased capacity of the rivers to carry water due to construction activities within the river channels and the disposal of waste materials. There is a growing recognition that many rivers around the world are experiencing long-term changes in rainfall patterns and subsequent alterations in flood conditions. Historical records have been proven to be a valuable source of information on the variability in rainfall and floods over the past 1 to 2 millennia in countries like Egypt and China (Valdiya, 2004). When there is no documentary evidence available, one must depend on proxies. Proxies are measurable parameters that indirectly give quantitative or qualitative information about climatic and hydrological variables like precipitation, run-off, and water discharge. Uninterrupted and dependable hydrological data is essential for comprehending monsoon flash floods and evaluating their risks. In addition to monsoon rainfall, factors like basin geology, basin morphology, channel geometry, and population growth combined with developmental activities are significant and warrant careful consideration in flash flood assessment.

iii. Flash flood risk mitigation

A combination of structural and non-structural techniques may be used to mitigate flash floods. Among the structural methods are: a) building embankments along rivers that are prone to flooding to fortify and elevate the banks in order to face rising floodwaters. b) Building reservoirs or dams to hold floodwaters that can be utilized for irrigation and the production of hydropower c) Improving the river channel by gradually deepening and dredging it to enhance its discharge capacity; however, this is an expensive procedure that might not permanently improve the river channel. Non-structural measures may include the use of satellite data for remote sensing and GIS applications, which enable near real-time flood monitoring, flood damage assessment, and flood risk-zone mapping, among other services. Forecasting of flash floods based on historical records may also be considered non-structural. Finally, it is imperative that the populace be empowered and educated about areas that are prone to hazards, how to escape these areas, and how to conduct rescue and relief efforts.

6.4. SWOT Analysis of Disaster Management in Kohima district

SWOT Analysis, developed by Albert S Humphrey in the 1960s, is a simple and fundamental approach used to evaluate an organization's capabilities, limitations, possible opportunities, and potential threats. The SWOT analysis approach involves extracting information from an environmental investigation and categorizing it into internal factors (strengths and weaknesses) and external factors (opportunities and threats). Strengths and weaknesses mostly pertain to internal aspects of your company, whereas opportunities and dangers often refer to external issues. The SWOT analysis is occasionally referred to as the Internal-External Analysis due of this rationale (Humphrey ,1969: 1974: 2005)). After the completion of this task, the SWOT analysis identifies factors that can aid the company in achieving its goals and identifies barriers that need to be conquered or minimized to get the intended outcomes.

The views of various experts cited in literatures, discussions and interviews with students, technocrats, NGOs and field observation have been utilised to depict the evaluation of SWOT analysis of disaster management in Kohima district of Nagaland. This analysis based on the available and acquired data sheds light on the various aspects- strength, weakness, opportunity and threats of the practice of disaster management in Kohima (Figure 6.1).

i. Strength

a. ***Local knowledge***: This factor is considered a very important aspect of strength in disaster management as a local resident is always liable to have knowledge of one's own land better than any outsider. Traditional knowledge of the land and familiarity with the terrain and climate of the region is one of the most rigid aspects in countering disaster and thus with more pressed efforts, one can be well prepared on the event of any disaster.

b. ***Volunteer works***: This factor also falls under the capsule of inclusivity, where a strong emotional bond to one's land will prove to be a resilient factor in trying ones best to leverage for disasters before, during and after and thus will result in effective management of disasters.

c. ***Government support***: This factor can also be seen as a strength considering that initiatives have been taken up by the government over the past few years in implementing a District Disaster Management Plan (DDMP) prompted by the high rate of disaster and casualties the district faced during the year of 2018. Since then, the District Disaster Management Authority (DDMA) under the Nagaland State Disaster Management Authority (NSDMA) have been doing a commendable job in executing the plan, thus providing a source of reliance during the onset of any kind of disaster.

d. ***Resilient communities***: Kohima being a district consisting of a population of a common cultural background depicts a high level of cohesion and resilience to disasters due to cultural practices and community solidarity.

ii. Weakness

a. ***Geographic vulnerability***: As is evident by now, the vulnerability of Kohima district owing to its steep and rugged terrain, along with its heavy monsoonal downpour coupled with the impact of climate change and having secured the seismic zone V in the seismic zoning of India which is the highest level of seismic risk, places Kohima in the most vulnerable zone to disaster specifically and specially due to its geographic implications, thus, making it the one factor which weighs the highest in the weakness scale of the SWOT analysis.

b. ***Negligible community awareness***: It has been observed through interview that the population though aware of the basics of disaster management are not equipped with the proper set of strategic knowledge on how to go about and what should be done when disaster strikes. It is important to state that the ignorance and lack of awareness on the importance of scientifically backed strategies for effective disaster management before, during and after has led to an increase in casualties during the onset of monsoon as a result of improper strategic awareness.

c. ***Negligible participation of local people and bodies*:** This is attributed to insufficient awareness programmes on disaster management and low level of disaster preparedness knowledge among the residents. There is a communication gap between the government and local communities and thus the lack of a decentralized information system to disseminate disaster related information effectively. Also, the lack of support for local leadership in disaster management roles. Economic and social constraints also play a role as economic constraints limits the ability of local communities to effectively take part while also social issues such as distrust in the government initiatives and lack of cohesion thus hindering further collective action.

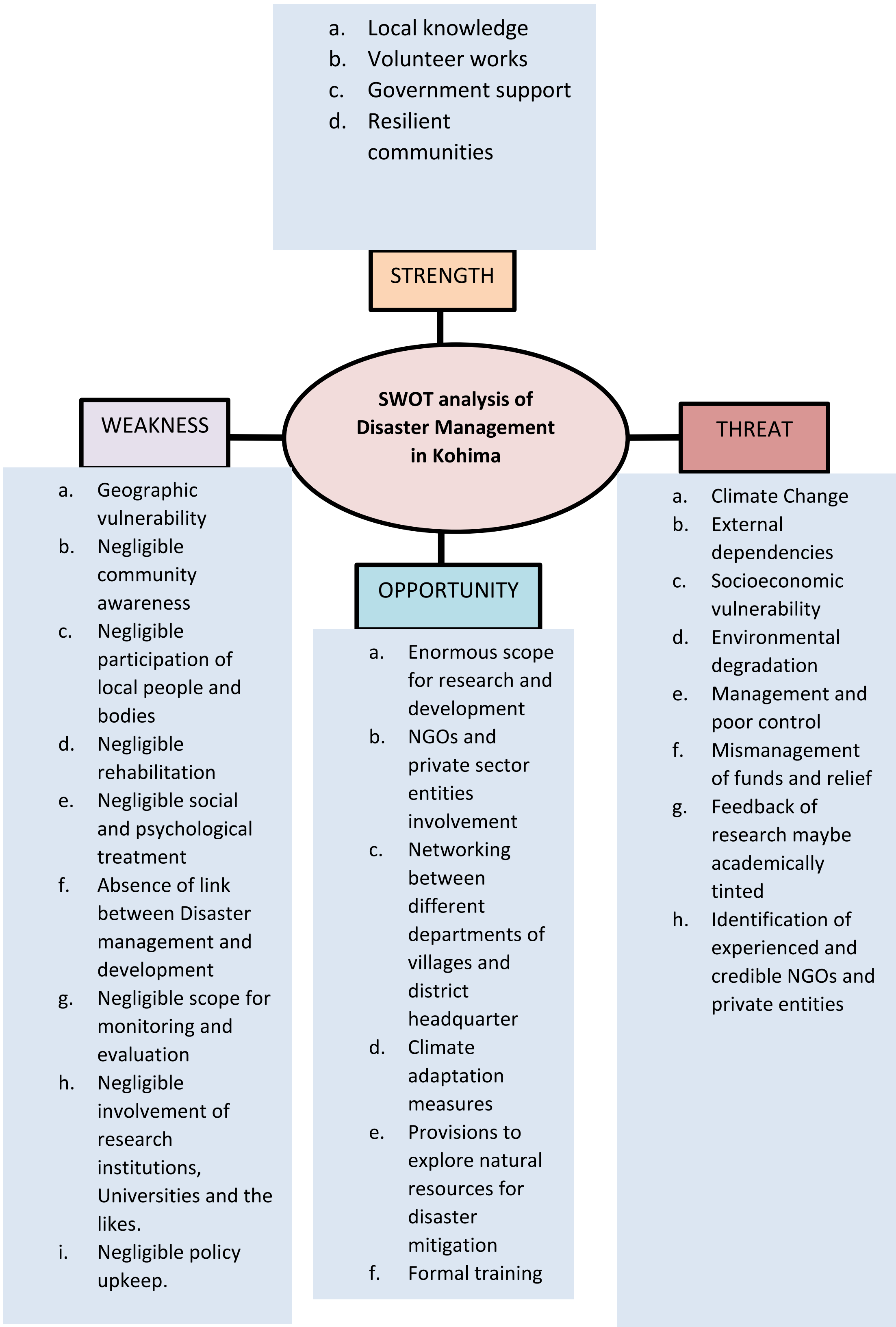


Figure 6.1: SWOT analysis of Disaster Management in Kohima

d. ***Negligible rehabilitation***: Rehabilitation efforts in Kohima district was found to be very poor. There exists a lack of long-term rehabilitation programmes and insufficient focus on rebuilding infrastructure and house post-disaster. The hilly and rugged terrain also contributes to the delay of efforts of rehabilitation especially during and after disaster. Early warning system and disaster forecasting capabilities are the major aspects that the district lacks in limiting the various steps that can be taken to provide effective rehabilitation even before the disaster which will ultimately decrease the number of casualties and property losses.

e. ***Negligible social and psychological treatment***: There is lack of mental health services and psychological support for disaster survivors, insufficient social support systems to help individuals and communities cope with trauma and inadequate training for emergency responders in providing psychological first aid. There exists a cultural stigma around mental health, making individuals reluctant to seek psychological help which leads to lack of awareness and education about mental health issues and their impact on disaster recovery. The trauma if not treated may result in to long term chronic illnesses. On the repeated onset of disasters, a traumatised individual who have had proper psychological treatment is better equipped to combat the effect of disaster than another individual who is deprived of the same.

f. ***Absence of link between Disaster management and development***: This has most frequent been the cause of increasing geomorphic hazards especially that of landslides in and around the region. The most intriguing developmental practice is that of road cutting and road construction without any proper scientific and technical knowledge of the threat such a practice is posing to the entire population. We have seen devastating incidents of rock fall and landslides along the highway of NH-29 over the years which are mostly triggered by ignorant road cutting practices. There is a lack of integration of Disaster Risk Reduction strategies in to development planning policies and short-term focus on disaster response rather than long-term resilience and sustainable development. To add to it, there is also a lack of political will and institutional inertia in integrating disaster management with development planning along with bureaucratic red tape and corruption hindering effective implementation of integrated policies.

g. ***Negligible scope for monitoring and evaluation***: A lack of comprehensive monitoring and evaluation (M&E) frameworks to assess the effectiveness of disaster management initiatives, insufficient data collection and analysis capabilities to inform decision-making, limited feedback mechanisms to learn from past disasters and improve future responses and limited availability of funds and resources for comprehensive disaster management, including M&E are evident in the disaster management strategy of the region.

h. ***Negligible involvement of research institutions, Universities and the likes***: There is a wide gap in the collaboration with academic institutions for research and development in disaster management. The use of scientific research and data to inform disaster preparedness and response strategies is a rare phenomenon in the arena of disaster management with limited academic resources and expertise being utilized in disaster risk reduction (DRR) and management efforts.

i. ***Negligible policy upkeep***: The disaster management authority in Kohima as well as in Nagaland in general does not have a framework policy that is crucial for a state like Nagaland that is considered most vulnerable to disasters. It functions under the mandate of policies brought about by the National Disaster Management Authority. However, every region has its own set of geographic set up and therefore, it is impractical to rely upon entirely on a policy that has been derived for the country as a whole. A more specific approach is necessary while framing a policy on disaster management for an administrative set up. To add to it, the policies are also outdated disaster management policies that do not reflect current risks and best practices with lack of regular reviews and updates to policies based on new research, technology, and lessons learned from past disasters. There exists inadequate enforcement and implementation of existing disaster management policies.

iii. Opportunities:

a. ***Enormous scope for research and development***: The scope of Research and Development (R &D) in Kohima is vast and large. There are various key areas under the scope of R & D that can serve as a means of significantly improving disaster preparedness, response, and recovery. Some of them are- Research into integrating real-time data from meteorological, geological, and hydrological sources to predict and warn against disasters like landslides, flash floods, and earthquakes, use of artificial intelligence (AI) and machine learning to enhance prediction accuracy, development of robust, resilient communication systems that can function during disasters, especially in remote areas, exploration of satellite and mobile communication technologies for effective dissemination of warnings and coordination during emergencies, research on locally available, cost-effective materials and construction techniques that can withstand natural disasters, development of retrofitting methods for existing structures to enhance their resilience, incorporation of sensors and IoT (Internet of Things) devices in critical infrastructure to monitor structural health and provide real-time data during disasters, development of resilient road and bridge designs that can withstand landslides and floods, Research on the link between deforestation, land use changes, and increased disaster vulnerability, studies on reforestation and afforestation techniques to stabilize slopes and prevent landslides, exploration of bioengineering methods to reinforce embankments and control erosion, documentation and analysis of indigenous knowledge and practices related to disaster management, research on the effectiveness of public awareness campaigns and education programs in changing behaviour and increasing preparedness, Studies on the psychological impact of disasters on affected populations, research on existing disaster management policies and identification of gaps and areas for improvement, comparative studies on best practices in disaster management from other regions and countries, research on the impact of climate change on the frequency and intensity of natural disasters in the region.

b. ***NGOs and private sector entities involvement***: The involvement of NGOs and private sector entities is crucial in enhancing disaster management in Kohima district. These organizations bring resources, expertise, and innovative approaches that can complement government efforts.

The NGOs can organize community awareness programmes and use various media, including social media, to disseminate information and educate the public; Organizing workshops and training sessions for community members, local leaders, and volunteers; Developing educational materials and disaster preparedness kits; formation of volunteer groups trained in first aid, search and rescue, and relief distribution; Deployment of rapid response teams to assist in the immediate aftermath of a disaster; Coordination and distribution of relief supplies such as food, water, shelter, and medical aid; Establishment of temporary shelters and provision of psychosocial support to affected populations; Involvement in rebuilding homes, schools, and community infrastructure; Implementation of livelihood restoration programs to help communities recover economically; Advocating for improved disaster management policies and practices; Participating in policy dialogues and contributing to the development of local and national disaster management strategies.

Private sector entities on the other hand has a very strong role to play as they can contribute on a number of practices such as Allocating Corporate Social Responsibility (CSR) funds to disaster preparedness, response, and recovery projects; Partnering with NGOs and local authorities to finance community-based disaster risk reduction (CBDRR) programs; Providing financial donations, equipment, and supplies for disaster relief efforts; Offering logistical support such as transportation, storage facilities, and communication tools; Development and implementation of advanced early warning systems using technologies like AI, IoT, and GIS; Analysing big data to improve disaster prediction and response strategies; Providing expertise and resources for building resilient infrastructure; Collaborating on projects to retrofit and strengthen existing structures against disasters; Developing and promoting business continuity plans to ensure that businesses can quickly recover from disasters; Training local businesses on risk management and disaster preparedness; Ensuring resilient supply chains to maintain the flow of goods and services during and after disasters; Collaborating with local suppliers to build their capacity to withstand disruptions.

Collaborative projects between the government, NGOs, and private sector will further enhance disaster management infrastructure and capabilities.

c. ***Networking between different departments of villages and district headquarter*:** By establishing clear communication channels, integrated information systems, joint training programs, resource-sharing protocols, and involving the community, Kohima can build a resilient and responsive disaster management framework. Collaboration and continuous improvement are key to ensuring that the district can effectively mitigate, respond to, and recover from disasters. Some of the practices of networking that can be accommodated are as follows:

Establishing Clear Communication Channels:

- Schedule regular meetings between village representatives and district officials to discuss disaster preparedness and response plans and use technology, such as video conferencing, to include remote villages in these meetings.

- Develop standard operating procedures (SOPs) for communication before, during, and after a disaster and ensure all stakeholders are aware of these protocols and have access to necessary communication tools (radios, mobile phones, internet).

Integrated Information Systems:

- Create a centralized database that contains information on resources, infrastructure, population, and risk assessments from each village.Implement an integrated early warning system that can disseminate alerts from the district headquarters to all village departments.Use multiple channels (SMS, loudspeakers, local radio) to ensure the warnings reach everyone.

Capacity Building and Training:

- Conduct joint training sessions for village and district officials on disaster management practices, emergency response, and use of technology.
- Focus on building local capacities for initial response, search and rescue operations, and first aid.
- Organize regular disaster simulation drills involving both village departments and district headquarters.
- Evaluate the effectiveness of these drills and update plans and protocols based on the outcomes.

Resource Sharing and Management:

- Maintain an updated inventory of resources (emergency supplies, equipment, trained personnel) at both the village and district levels.
- Develop a resource-sharing protocol to ensure that villages can quickly access district resources during emergencies.
- Establish mutual aid agreements between villages and district headquarters for sharing resources and support during disasters.
- Formalize these agreements to ensure clarity on roles, responsibilities, and resource allocation.

Community Involvement and Feedback:

- Form community disaster management committees in each village that work in tandem with district authorities.
- These committees can serve as liaisons, ensuring that community needs and feedback are communicated to district officials.
- Involve community members in disaster planning and decision-making processes.
- Conduct public awareness campaigns and feedback sessions to improve disaster management strategies.

Disaster Management Committees:

- Establish Disaster Management Committees at the village level, comprising local leaders, volunteers, and representatives from various departments (health, education, agriculture).
- These committees should coordinate with the District Disaster Management Authority (DDMA).
- Form a District Coordination Committee that includes representatives from all village-level committees and key district departments.
- This committee should meet regularly to review disaster preparedness plans, conduct risk assessments, and coordinate response efforts.

Information and Communication Technology (ICT):

- Develop a digital platform or mobile application to facilitate real-time communication between village departments and the district headquarters.
- This platform can be used for sharing alerts, updates, resource requests, and reports.
- Use data analytics tools to analyse information collected from villages and improve disaster response strategies.
- Implement predictive analytics to forecast potential disasters and plan accordingly.

Legal and Institutional Framework:

- Develop policies and frameworks that mandate cooperation and coordination between village departments and district headquarters.
- Ensure these policies are supported by legal provisions that define roles, responsibilities, and accountability.
- Establish dedicated units or officers at the district level responsible for coordinating with village departments on disaster management.
- Provide institutional support in terms of funding, training, and resources to strengthen these units.

d. ***Climate adaptation measures***: Climate adaptation has a very big role to play in disaster management as a result of climate change which have been accelerating environmental hazards all in all. A number of measures can be taken to adapt to the ever-changing climate pattern and some of them are as follows:

- Implementing soil conservation techniques such as terracing, contour ploughing, and agroforestry to prevent soil erosion and maintain fertility.
- Promote rainwater harvesting and the construction of small check dams and ponds to enhance water availability during dry periods.
- Develop and implement integrated watershed management plans to conserve water, improve soil health, and enhance biodiversity.
- Involve local communities in watershed management activities to ensure sustainable practices.
- Promote reforestation and afforestation programs to restore degraded lands and enhance groundwater recharge.
- Use native and climate-resilient tree species to ensure long-term sustainability.
- Update building codes and standards to ensure that new infrastructure is designed to withstand extreme weather events.
- Promote the use of resilient construction materials and techniques.
- Identify vulnerable infrastructure and prioritize retrofitting to enhance resilience to climate impacts.
- Focus on critical infrastructure such as schools, hospitals, and transportation networks
- Encourage the development of parks, community gardens, and green roofs.

- Establish and manage protected areas to conserve biodiversity and protect critical habitats.
- Engage local communities in the management and conservation of these areas.
- Implement ecosystem restoration projects to rehabilitate degraded landscapes and improve ecosystem services.
- Involve local communities in conservation efforts through community-based natural resource management programs.
- Provide training and support for sustainable livelihood practices that align with conservation goals.
- Promote alternative livelihoods that reduce pressure on natural resources, such as ecotourism, agroforestry, and handicrafts.
- Train healthcare workers on climate-related health risks and response strategies.
- Conduct public health awareness campaigns to educate communities about climate-related health risks and preventive measures.
- Develop social protection programs to support vulnerable groups, including the elderly, children, and marginalized communities, in coping with climate impacts.
- Ensure that disaster relief and recovery efforts are inclusive and equitable.
- Promote community resilience through capacity-building programs that enhance local knowledge and skills in disaster preparedness and response.
- Foster community networks and support systems to improve social cohesion and collective action.

e. ***Provisions to explore natural resources for disaster mitigation***: Exploring and utilizing natural resources can significantly contribute to disaster mitigation in Kohima district. By leveraging these resources sustainably, the district can enhance its resilience to natural disasters. Here are provisions and strategies to explore natural resources for disaster mitigation:

- Installing solar panels on public buildings, homes, and schools to provide reliable energy during disasters when conventional power sources may be disrupted.
- Developing community solar projects to enhance energy security and reduce reliance on fossil fuels.

- Exploring wind energy potential in suitable areas to diversify energy sources and enhance resilience.
- Encouraging the use of small-scale wind turbines for remote and off-grid communities.
- Developing small-scale and micro-hydropower projects that have minimal environmental impact and provide reliable energy.
- Using hydropower to support local water supply and irrigation systems
- Promoting terracing and contour farming to reduce soil erosion and improve water retention on slopes.
- Encouraging agroforestry practices that integrate trees with crops to enhance soil health
- Implementing zoning regulations that prevent construction in high-risk areas such as floodplains and steep slopes.
- Encouraging land use practices that enhance natural resource conservation and reduce disaster risks.

f. ***Formal training on disaster management*:**

Formal training on disaster management has become a requisite where the community can be educated in the form of Comprehensive course and basic courses including introductions on topographical configuration, structural development and constructions and awareness programmes including mock drills.

We require the preparation, planning, and exercises that give us scientific data on the models and scales of numerous disasters in order to handle any unforeseen circumstance effectively. The impoverished are the most at risk groups in these catastrophes. Therefore, it's important to encourage kids to be ready for any situation. In order to save lives and alleviate suffering as quickly as possible, delivering emergency relief and rescue operations requires a quick and fast response. We must be fully outfitted with the newest technologies. While it cannot stop the calamity from happening, it can greatly lessen its effects.

iv. Threat:

a. ***Climate Change***: Kohima is no longer unaffected by the various atrocities of climate change. Extreme rainfall patterns, as well as seasons of complete lack of rainfall coupled with increasing temperature have given rise to various hazards and disasters such as soil erosion and landslides, seasons of drought and heatwaves. With the ongoing trend of climate change, Kohima is likely to face more severe cases of geomorphic hazards that will directly and indirectly affect lives to a greater extend.

b. ***External dependencies***: External dependencies play a crucial role in disaster management for Kohima district. These dependencies can provide necessary support but also pose risks if they are not well-coordinated or if they fail during critical times. Understanding and managing these dependencies is key to building a resilient disaster management system. Managing external dependencies in disaster management requires a strategic approach that emphasizes diversification, local capacity building, effective coordination, and investment in resilient infrastructure. By addressing these dependencies proactively, Kohima district can enhance its disaster preparedness and response capabilities, ensuring a more resilient and sustainable future for its communities.

c. ***Socioeconomic vulnerability***: Socioeconomic vulnerability in disaster management refers to the susceptibility of individuals, communities, and regions to the impacts of disasters, influenced by social and economic factors. In Kohima district, several aspects contribute to socioeconomic vulnerability, which need to be addressed to enhance overall disaster resilience. Economic instability hinders recovery efforts and prolong the impact of disasters. Many homes are constructed without proper adherence to building codes and standards, making them vulnerable to natural disasters such as earthquakes and landslides while Informal settlements are often located in high-risk areas, such as slopes and riverbanks, increasing exposure to hazards. Cultural beliefs and practices may also hinder the adoption of modern disaster management strategies.

d. ***Environmental degradation***: Environmental degradation significantly impacts disaster management in Kohima district by increasing vulnerability to natural hazards and reducing the effectiveness of mitigation efforts. Key Aspects of Environmental Degradation in Kohima District. Here are some of the environmental degradation activities practiced in Kohima and their impacts:

Deforestation:

Causes: Logging for timber and fuelwood, expansion of agricultural land and urban areas.

Impacts: Increased soil erosion and landslide risks, loss of biodiversity and natural habitats, reduction in natural barriers that protect against floods and storms.

Soil Erosion:

Causes: Unsustainable agricultural practices, such as slash-and-burn farming, Deforestation and overgrazing by livestock.

Impacts: Decreased soil fertility, affecting agricultural productivity, Increased sedimentation in rivers and streams, leading to reduced water quality and higher flash flood risks.

Water Resource Depletion:

Causes: Over-extraction of groundwater for irrigation and domestic use, pollution of water sources from agricultural runoff and waste disposal.

Impacts: Reduced availability of clean water for drinking, agriculture, and industry, increased vulnerability to droughts and water scarcity.

Loss of Biodiversity:

Causes: Habitat destruction due to deforestation, urbanization, and agricultural expansion, overexploitation of wildlife and plant species.

Impacts: Loss of ecosystem services that support agriculture, water regulation, and climate resilience, increased vulnerability to pest and disease outbreaks.

Climate Change:

Causes: Greenhouse gas emissions from deforestation, agriculture, and fossil fuel use, changes in land use and land cover.

Impacts: More frequent and intense extreme weather events, such as heavy rainfall, floods, and droughts, altered weather patterns affecting agriculture and water resources.

e. ***Management and poor control*****:** Challenges in management of disaster hinders the effectiveness of disaster response and recovery and thus following are some of the key challenging factors experienced by Kohima district in disaster management: lack of co-ordination and communication, fragmented efforts and poor coordination among various government departments, NGOs, and private sector entities and lack of a unified command structure and clear roles and responsibilities during disaster response, delays in disseminating critical information and early warnings to affected populations, insufficient use of modern technology and data analytics in disaster management, reliance on outdated methods and tools for disaster preparedness and response, inadequate infrastructure and logistical support for efficient disaster response and relief distribution, incomplete or outdated disaster management policies and regulations and ack of accountability and transparency in disaster management operations are some of the various threats in line of co-ordination and communication faced by the district of Kohima.

f. ***Mismanagement of funds and relief***: Management of funds and relief in disaster management also serves as a major setback in its effectiveness due to various key factors some of which are, insufficient transparency in the allocation, disbursement, and utilization of disaster management funds, lack of clear guidelines and oversight mechanisms to track the flow of fund , instances of corruption and embezzlement of funds intended for disaster relief and recovery, diversion of relief resources for personal or political gains, fragmented efforts and poor coordination among various agencies and organizations involved in disaster relief, duplication of efforts and resources due to lack of a centralized distribution system, lack of robust monitoring and evaluation mechanisms to assess the effectiveness and efficiency of fund utilization and relief distribution, absence of real-time data and reporting systems to track the progress and impact of relief efforts, limited avenues for affected communities to provide feedback on the adequacy and appropriateness of relief assistance and lack of mechanisms to incorporate feedback into ongoing and future disaster management efforts.

g. ***Feedback of research maybe academically tinted***: This is a dormant underlying factor in most of disaster management strategies. Researches done on disaster management are either neglected or tinted for various reasons and thus as a result proper managing tools are not incorporated and as a consequence, we are not able to properly manage disasters or potential hazards as deemed fit. There are also various cases where models of disaster management that are suggested are very theoretical and impractical and one is unable top apply to one's reality and thus the various plans and policies laid out remains published without any practical implications.

h. ***Identification of experienced and credible NGOs and private entities*****:** This process involves thorough evaluation and verification of organizations' capabilities, track records, and commitment to ethical practices which has become a shortcome as Identifying experienced and credible NGOs and private entities involves a systematic approach to evaluate their track record, expertise, transparency, and community engagement and many are not willing to put in the effort required for such a systematic approach thus relying on unsafe immediate response practices.

The SWOT analysis on disaster management in Kohima thus reveals various factors of strength that the district possesses in managing the disasters it is prone to effectively. The number of list of strengths however falls short in comparison to the rest of the 3 factors thus throwing light on the weakness, opportunities and threats the region possess in management of disaster. This analysis reveals the various shortcomings in disaster management in the region and indicates that the existing policies and their implementation are more concerned about the immediate relief and rescue operations. The basic important aspect of disaster management i.e. preparedness, mitigation and rehabilitation are not given much importance and are highly negligible. The economic, socio-politico and ecological aspect plays a crucial role in leveraging disaster management in the region, which was however found to be tinted, corrupted or negligible to an extend consequently giving way to unprecedented and avoidable hassle to occur in disaster management.

6.5. Economic aspects

The economic aspect of disaster management problem describes the scarcity of resources where limitation of funds leads to problems like delay in relief and rescue operations, rehabilitation of people residing in very sensitive zones, lack of proper medical care, lack of education and awareness and more. For a region like Kohima, where increasing frequency of disasters put pressure on the already poor economy, it is of utmost importance to give emphasis on optimum use of available funds so that with limited resources, maximum results can be obtained in the field of disaster management.

6.6. Socio-politico aspects

This aspect reveals the political, socio-cultural and socio-economic condition of the society. As discussed in the preceding sections, the discrimination in survey, delay in relief, poor monitoring and evaluation, poor representation of NGOs, lack of coordination and false promises reveals the political shortcomings prevailing in disaster management and the mutual trust endowed on each other. Mis-utilization of funds, poor cooperation from the people, psychological shock, vulnerability of the population are the various problems in Kohima representing the socio-cultural condition of the society.

6.7. Ecological aspect

The most important aspect in any disaster management framework i.e., the environment, is seen to be neglected to an extensive degree as evident in the heavy developmental activities of deforestation and road construction. For an unstable and fragile area like Kohima, the environmental aspect plays a crucial role as it includes eco-friendly development and other related activities which checks the deteriorating environmental conditions which results to disaster mitigation, which brings us to clubbing sustainability and hazard mitigation into one aspect.

6.8. Sustainability in Hazard Mitigation

This includes a harmonical functioning of all the above three aspects or systems, viz., the economic aspect, socio-politico aspect and the ecological aspect where the expansion of each of the domains should develop but not at the expense of the other domain. A community seeking to improve its quality of life through sustainable development will benefit from a political system that encourages citizen participation in all aspects of the planning and decision-making processes; an economic system that is self-reliant and has long-term productive capabilities; and a social system that facilitates cooperation and collaboration throughout the development process (Daly, 1990).

Regarding social viability in the face of hazard-related disasters, a community must balance the needs of its citizens for housing and access to basic public services and facilities. Local leaders, for example, must consider the competing needs of residents in high-hazard areas, who may have limited ability to rebuild after a disaster, against those of homeowners in environmentally sensitive areas where rebuilding may not be in the public interest. Other significant social consequences of hazard-related disasters that reduce overall community sustainability include loss of security, severe stress and anxiety, diminished trust in government, and disruption of familiar environments and daily routines (DESA, 2005; FEMA, n.d.).

The economic vitality of a community is directly impacted by its level of disaster resistance. The three main objectives of community disaster recovery are to retain existing businesses, encourage new and continued economic development, and ensure that businesses are rebuilt sustainably (Daly, 1990). Therefore, a key element of a sustainable economy is reducing the vulnerability of local businesses and economic infrastructure, either by keeping them out of high-risk areas or by implementing disaster-proofing measures when relocation is not feasible.

Environmental sustainability maintains the integrity of biological and physical systems by limiting environmental degradation and preserving natural systems such as wetlands, floodplains, dunes, and active fault or landslide zones. These natural systems enhance a community's resilience to natural hazards.

Establishing the critical link between hazard reduction and sustainable development is essential for planners and policymakers, especially as urban expansion and development increase in high-risk areas. Hazard mitigation techniques support communities in achieving their broader goals of social welfare, environmental preservation, and economic development. By providing disaster-resistant housing, jobs, transportation, and public services, communities that actively engage in hazard mitigation planning become more resilient and sustainable. Reducing the long-term risks of hazards not only benefits communities but also serves as a catalyst for positive change. The long-term benefits of implementing a risk mitigation planning process are undeniable.

6.9. Strategies on coping with geomorphological hazards in general

In the light of the four types of geomorphological hazards (earthquake, soil erosion, landslide and flash floods) along with the role of various hydrometeorological factors in the degradation of the land discussed in this research, there are a sequence of strategies that have been understood to help in the coping of hazards, if not prevent.

i. **Mapping of Areas Prone to Hazards**

   Hazard-zoning Maps are the essential need for implementing hazard-coping strategies. This activity relies on understanding the geological context, tectonic conditions, and topography of the terrain. Hazard maps must be created by systematically comparing risks deduced from various causative elements and the actual hazardous occurrences identified via field surveys, until the most accurate correlation is established between the two. Hazard maps have little use unless they are created at a size that is suitable for practical implementation.

ii. **Risk assessment**

   It involves creating a map of infrastructure that displays a) human settlements, including building structures, and b) significant buildings, roads, and bridges. c) demographic representations displaying the spatial arrangement and concentration of individuals within a given area. This facilitates the identification of the components that are vulnerable to the hazard, the precise and overall risks associated with it, and ultimately allows for the estimation of the potential economic damage in the event that the hazard occurs as predicted.

iii. Plan for Preparedness in the Event of Hazards

Valdiya (2004) defines a hazard preparation plan as a compilation of items on an agenda, which include the following:

a. Hazard zoning maps assume the likelihood of an occurrence happening at a certain site during a certain time period. Consequently, it is necessary to do an initial evaluation of the likelihood of events.
b. Implementing steps in conjunction with hazard zoning to mitigate the intensity and frequency of risks, hence decreasing the degree of resulting damage.
c. Providing education to individuals on the characteristics, origins, and outcomes of the hazard, the potential dangers associated with it, and the probable effects on both natural ecosystems and the socioeconomic framework of society. The information should be promptly shared via several media channels, accompanied by counselling on various strategies to manage the hazards, such as evacuating the affected region.
d. Coordinating the mobilization of relief measures such as medication, proper sanitation, food, and shelter, which are necessary in the event of a catastrophe. It is crucial to emphasize that the whole range of entities, including the government, non-government organizations, voluntary groups, and the public, must be engaged in these activities.

iv. Legislation and policies for the management of hazards

Public policy pertaining to hazard management necessitates the formulation and implementation of legislation and regulations aimed at preventing and limiting development in regions that have been designated as prone to hazards in hazard zoning maps. The government has a responsibility to establish regulations for constructing and maintaining buildings and utility structures in inhabited areas. These regulations should be enforced by the administrative bodies of municipalities and panchayats.

A viable approach to tackle the issue would include implementing a range of deterrents, such as:

a. Withholding government aid for the construction of infrastructure like roads, hospitals, schools, bus stops, etc. in recognized high-risk areas.

b. Lack of access to bank financing for the building and maintenance of dwellings and other structures in these areas.
c. Refusal or removal of vital utilities or facilities, such as water and power. Remove public infrastructure such as sewage, telephones, buses, and taxis from places that are prone to hazards.
d. Refusal of insurance coverage for risks associated with hazards in areas prone to hazards.

Nevertheless, in a democratic society, it is essential for the government to provide fundamental necessities to its citizens (Bhandari, 2002). The government is unable to financially support the continuation of these services and cannot allow individuals to experience hardship. If a region is prone to dangers or harmed by them, the government is obligated to expedite the development of highways, construct more hospitals and schools, reinforce building and utility infrastructure, and undertake necessary repairs. Promoting insurance coverage for risks should be advocated. However, this will incentivize individuals to stay in regions prone to dangers and engage in activities that will further exacerbate the risks associated with these hazards. The government may buy hazard-prone lands to build recreational parks, playgrounds, fuel farms, horticulture, and vegetable gardens.

Monetary incentives may also be effective:

a. Promoting the investment of business individuals in hazard mitigation measures via the provision of income tax credits.
b. Granting tax exemption for privately issued bonds used in the process of retrofitting buildings and facilities.
c. Central government provides matching funding for upgrading state and local government important infrastructure.
d. Establishing a Disaster Insurance Corporation that offers insurance and reinsurance.

Furthermore, it is imperative that state and local governments enhance their readiness to execute hazard mitigation efforts, with the aid of training and exercises, in conjunction with the incentives and disincentives offered by the central government. It is important to promote and support individuals in taking on more proactive roles in disaster planning, response, and recovery initiatives.

It is certain that post-disaster money serves as a kind of motivation, particularly when the government assumes full responsibility for covering all expenditures associated with catastrophe management. It might be seen as a kind of compensation for failing to prioritize previous efforts in disaster management planning. It is consequently recommended to allocate funds towards hazard preparation strategies rather than towards relief and restoration efforts.

6.10. Suggestions for enhancing disaster management in Kohima district and Nagaland as a whole:

i. **Creation of a Centre dedicated to the prevention and control of disasters**: Despite a significant increase in investment in disaster mitigation and management, it has been found to be inadequate in effectively reducing disasters and there are noticeable deficiencies in various areas. Due to its high susceptibility to geomorphological disasters and its location in seismic zone V, it is crucial to identify, measure, and address deficiencies in knowledge, training, and services in order to effectively mitigate the impact of disasters. For the Centre for Disaster Mitigation and Management, achieving excellence in service delivery requires strict adherence to standards for high-quality research, training, and education. To achieve excellence, it is necessary to have competent faculty, sufficient equipment, proper infrastructure, and up-to-date course materials. For teaching, research, and resources, it is essential to establish strong partnerships with both national and international experts and institutions. The proposed centre has several typical functions, which include:

a) Enhance understanding and proficiency in various facets of disaster management, including mitigation, preparedness, emergency response, and recovery.

b) Apply knowledge across various local, state, national, and global contexts in order to generate innovative solutions.

c) Establish databases and develop expertise that can be readily utilized.

d) Recognize and record optimal methods (conventional/efficient methods, etc.) and create local materials for their adapted reproduction.

e) Create instructional modules for individuals at all skill levels and provide training to expert trainers.

f) Commence Value Added Courses, Diploma Courses, and Short-Term Courses at the beginning.

g) Implementation of Postgraduate (P.G.) and Doctor of Philosophy (Ph.D.) programs.

Conduct cutting-edge research in disaster management in North East India and India to pave the way for future research and practical applications of the findings.

i) Act as a forum for public policy consultations.

j) Uphold the standards in training and education through the issuance of certifications to acknowledge exceptional performance in terms of quality.

ii. **Public Collaboration**: A national directory of all non-governmental organizations (NGOs) with trained volunteers is necessary for coordinated relief efforts and community capacity building.

iii. **Medicare service**: The healthcare needs of individuals affected by disasters require more significant and focused attention than they have received so far. It is necessary to establish a network of laboratories in areas prone to hazards, which will serve the purpose of testing infections and diseases as well as monitoring disease outbreaks. Another crucial aspect of healthcare involves addressing the psychological issues of fear, depression, and phobia among individuals through specialized counselling. The participation of social scientists and psychologists will be required for this.

iv. **Legislative Measures**: The government has a responsibility to create and enforce laws and regulations to prevent or limit the development and use of lands that have been scientifically identified and officially declared as prone to hazards. To effectively reduce the tendency of occupying highly hazardous areas, it is recommended to implement legislative measures that impose disincentives. These disincentives may include denying government assistance for infrastructure development, such as roads, hospitals, and schools, in identified hazard-prone areas. Additionally, individuals in these areas may be denied loans from banks, essential supplies, and insurance coverage. Alternatively, the government has the option to exercise its power of compulsory acquisition to obtain the areas for alternative land use, such as parks, sanctuaries, and other purposes.

It is advisable to differentiate between a critical structure and an ordinary structure using appropriate legal means. A critical structure refers to a high dam or a high-rise building that is more susceptible to extensive damage compared to an ordinary structure, resulting in a greater catastrophic impact. Therefore, it is crucial to prioritize the implementation of building codes, the enforcement of bye-laws, and the assessment of risks associated with existing urban buildings and structures.

Additionally, conducting micro-zonation of major urban areas should be considered a top priority. Overall, for the education, training and research, an Advanced Centre for Disaster Mitigation and Management in Nagaland is recommended.

References

Bhandari, R.K. (2002). Seismic microzonation. Chennai: Centre for Disaster Mitigation and Management, *Anna University*, 198 pp

Gupta, M.C., Sharma, L.C., & Tamini, B.K. (2001). Manual on Natural Disaster management in India. New Delhi, *Department of agriculture & Cooperation, Government of India*. 204 pp

Government of India. (1999). Foreign Exchange Management Act (1999), *Directorate of Enforcement, Department of Revenue, Ministry of Finance*

Humphrey, A.S. (2005). History Corner: Swot Analysis for Management Consulting [WWW Document]. *SRI Alumni Association*. URL. https://archive.sri.com/sites/ default/files/brochures/dec-05.pdf. accessed 1.23.2023.

Humphrey, A.S. (1974). Getting management commitment to planning: a new approach. Long. Range Plan. 7, 45–51. https://doi.org/10.1016/0024-6301(74)90078- 8.

Humphrey, A.S. (1969). Letter from Albert S. Humphrey to Birger Lie with the News that Joe McPherson “The Chair from Industry” from Dow Chemical Comes to Work for LRPS/TAPP. RFS & OJB got their wish.

Reddy, R.K., Ramanaiah, Y.V., Kumari, A.K., & Subbiah, S. (Ed.) (2009). Natural hazards and Disasters Essays and Impact and management, *International Conference Volume. Department of Geography, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India*

Satendra. (2001a). Disaster And Development; Silver Jubilee Issue of Employment news, Publication Division, *Ministry of Information and Broadcasting*, New Delhi

Satendra. (2001b). Dealing with Disaster, Dow to Earth, vol 9 No. 23, *Centre for Science and Environment*, New Delhi

Satendra. (2003). Disaster management in the Hills. *Concept Publishing Company*, New Delhi

Starkel, L. (1972a) The role of catastrophic rainfall in the shaping of the relief of the lower Himalaya (Darjeeling Hills), *Geographia Polonica*, 21: 103–160.

Starkel, L. (1972b) The modelling of monsoon areas of India as related to catastrophic rainfall, *Geographia Polonica*, 23: 151–173.

Thigale, S.S. & Khandge, A. (2000). Landslides in Western Ghats of Maharashtra. In: *Contributions to environmental geoscience,* ed. A.M. Pathan and S.S. Thigale. New Delhi: Aravali Books Intern. 161-174

United Nations. (2023). Global Sustainable Development Report, *Department of Economic and Social Affairs*

Valdiya, K.S. (1987). Environmental geology. Indian Context. New Delhi: Tata-McGraw Hill. 583pp

Valdiya, K.S. (2001). Dynamic Himalaya. Jawaharlal Nehru Centre for Advanced Scientific Research. Universities Press (India) Limited

Valdiya, K.S. (2004a). Coping with Natural hazards: Indian Context. (Ed.). The National Academy of Sciences, Allahabad

Valdiya, K.S. (2004b). Geology, Environment and Society. Universities Press (India) Private Limited, 3-6-752, Himayatnagar, Hyderabad 500 029 (A.P). India

Summary and Conclusion

With an area of 978.96 sq. km., or 5.90% of the state's total area, Kohima is a mountainous district located in the extremely northeastern Indian state of Nagaland. Kohima district of Nagaland, receives substantial precipitation during the monsoon season, with an average annual rainfall of 2500 mm. The district, with a population of 267,988, is situated in a volatile region of India characterized by frequent seismic disturbances. Kohima possesses a diverse range of plant and animal life and is prone to natural risks caused by its young geological formations, steep inclines, heavy rainfall, and insufficient land management practices. The soil consists of sedimentary elements and has a significant degree of porosity, rendering it susceptible to erosion and landslides. The study area comprises tertiary sedimentary formations from the Disang and Barail groups, predominantly consisting of sandstone and shale. The region is experiencing environmental disturbances due to climate change, resulting in both excessive rainfall and drought-like circumstances. These changes are impacting water shortages and the agricultural sectors. The combination of rapid population increases, insufficiently supported development initiatives, and poor disaster management strategies has intensified the occurrence of hazards. Businesses and institutions in Kohima, particularly those located along highways, are at a significant risk of being affected due to frequent delays. Consequently, this has resulted in significant perils for both persons, livestock, and enterprises in the area. The study location, Kohima district, is located in the northeastern portion of India and is known for its geological instability. The region has persistent rainfall throughout the pre-monsoon and inter-monsoon periods, making it especially vulnerable to geomorphological dangers like as landslides and flash floods. Every year, the region faces substantial disruption due to intense rains, which worsens the already precarious geological structure of the territory. Landslides lead to road closures, property damage, vegetation loss, and the obstruction of rivers and streams. In addition to natural causes such as lithology and climate, the development of highways has worsened the issue by leading to increased deforestation, extraction of earth materials, and deposition of these materials on land. This has escalated the land's burden, resulting in its subsidence.

The focus on risks and catastrophes in the subject of Geography has been steadily growing since its establishment as an academic discipline. Geomorphological risks, such as floods, slope movements, soil erosion, water quality risk, desertification, unexpected weather changes, and wildfires, are classified as natural hazards. Geomorphological dangers refer to the potential occurrence of highly dynamic or widespread damaging processes in a certain location and timeframe. The geographical viewpoint of geomorphic hazards encompasses the distribution, location, processes, mobility, clusters, accessibility, patterns, linkages, and changes of these hazards. Geomorphic hazards arise from the instability of surface features on Earth and are caused by any alteration of landforms that negatively effects the stability of a specific location and has detrimental socio-economic consequences for human activities.

Kohima is characterized by an undulating plateau with towering hills and peaks. The district's topography is influenced by the arrangement, mechanisms, and progression of landform development. The Japfii mountain, the highest peak in the region, stands at 3014 meters above mean sea level. The district has an average height of around 1261 meters and is categorized according to elevation. The Undulating zone, which covers the northwestern and partially northeastern sections of the district, has an altitude range of 204 m to 829 m above sea level. It is characterized by a gentle slope and prominent rivers. The Zubza valley, covering 20% of the land area, is part of this zone. The Piedmont region, covering 60% of the district, has gentle inclines and a notable population density. The Dissected Highland Plateau, located in the southern part of the district, has a steep slope and dendritic streams. The Structural Hills and Mountains zone, with the highest elevation, spans 5% of the total area and features prominent hills with gradients exceeding 35 degrees. Japfu, the second tallest mountain in the area, is situated in Nagaland.

The Kohima region in Nagaland is known for its rugged topography and rocks from the Disang and Barail formations. The town area is primarily composed of Disang rocks, while the southern part is mainly made of Barail sediments. Kohima is located within the Kohima synclinorium, a geological structure that includes materials from the Upper Cretaceous era to the present. The district's geological sequence includes the Disang group, which consists of dark grey and easily split shales, phyllitic shale, siltstone, sandstone, and khaki or buff-colored shales. The Barail groupings consist of distinct entities or categories, with the Barail rock formation covering a substantial amount of the southwestern region. The Surma ethnic groups consist of shales and sandstones, with some conglomerates that get thinner towards the north. The Tipam rock formation is found in the northern part of the area, mostly composed of ferruginous sandstone with notable clay deposits and a considerable thickness. The Disang groupings are characterized by spheroidal weathering, compact and solidified phyllitic shales, siltstone, sandstone, ferruginous and quartzite rocks, and khaki-colored shales.

The Kohima district's soils are derived from tertiary rocks, specifically from the Barail and Disang groups. The Barail group consists of alternating shales and sandstones, while the Disang lithology is made up of non-fossil-bearing shales, slates, and phyllites. The topography is characterized by gently sloping hills, terraces, and valleys. The predominant soil types are Fine Loamy Lithic Udorthent, Umbric Dystrochrepts, Fine Typic Paleudults, Typic Hapludults, and Fine-Loamy soils. The high relief geomorphology includes prominent ridges, elevated structural hills, and moderately elevated structural hills. The lithology underlying the area consists of Barail group rocks, specifically shales and sandstone.

The Kohima district in northeast India has been classified into four distinct microclimatic zones based on meteorological data from 2011 to 2021. These zones are humid tropical (elevation below 900m), humid subtropical (elevation between 900m and 1750m), humid temperate (elevation between 1750m and 2600m), and humid sub-temperate (elevation between 2600m and 3450m). Temperature variations within these zones are significant, with lower elevations characterized by a humid tropical climate and higher elevations characterized by a humid temperate climate. The highest recorded temperature in August is 29.09°C, while the lowest in January is 5.14°C. The region experiences large variations in monthly average minimum and maximum temperatures, with lower elevations characterized by a humid tropical climate and higher elevations characterized by a humid temperate climate. The Kohima district has experienced an average yearly rainfall of 1659.46 mm between 2011 and 2021, with the most amount of rainfall occurring in July and the lowest in December. The monthly average minimum and maximum rainfall in the region varies significantly, ranging from a humid tropical climate at lower elevations to a humid temperate climate in higher elevations. The mean annual humidity in the air is 83.83%, with the highest humidity in July at 96.07% and the lowest in February at 72.65%. Monthly average minimum and maximum humidity vary significantly over the region, ranging from a humid tropical climate in lower elevations to a humid temperate climate in higher elevations. Humidity reaches its greatest levels often in July, coinciding with peak temperatures and rainfall.

It is inferred that around 82% of the total area (978.96 km2) in the research region consists of natural landscape. This includes 18% thick forests, 63% open forest land, 0.39% water bodies, and 0.81% shrubs land. Out of the total area, 18.14% is categorized as anthropogenic landscape, which includes 8.72% as build-up area, 1.26% as wasteland, and 8.16% as agricultural land.

Nagaland is known for its indigenous culture and diverse religious organization. The Kohima district, the second most populous district, has a population of 1,980,602. The population density in Kohima is varying between Kohima Sadar (55.35%), Botsa (6,695), and Jakhama, Chiephobozou, Sechu-zubza, and Kezocha (16.12%, 9.33%, 8.23%, and 7.80%, respectively).

The 2011 census data shows that Tseminyu and Cheiphobozou have experienced a decrease in population, while other areas have seen growth. Jakhama circle has shown the highest percentage of expansion due to its central location for institutions and its exceptional road access to the primary town. Kohima is characterized by its hilly and uneven topography, with settlements generally situated on the crests of several hills. The capital, Kohima, is experiencing northward expansion due to increasing population and limited land available for building. The dispersion of settlements in the villages is greater than in the urban region, driven by individuals seeking job, education, and other opportunities. Planning authorities are considering building educational institutions and related facilities in nearby villages to address traffic congestion and improve the economic development of their respective regions. However, some rural settlements are susceptible to natural disasters, as they were not built with consideration for resistance against geological hazards. In conclusion, Nagaland's population dynamics and demographic makeup are influenced by its unique topography, population density, and the ability of communities to withstand and recover from natural disasters.

The physical geography of the Kohima district in Nagaland, India indicates that the region has a complex and highly stressed geophysical setup, including active tectonics, geological background, geomorphology, relief pattern, slope gradient, drainage system, soil, and vegetation. Additionally, the region experiences dynamic hydrological conditions, with a decrease in base flow during the dry season and an increase in flood flow during the rainy season. Furthermore, the area is characterized by climatic conditions such as rising average temperature, evaporation, and subsequent high intensity rainfall. On the other hand, the anthropogenic factors (such as land use pattern, cultural profile, demographic profile, occupational structure, literacy, settlements, education, and awareness of environmental issues) that were studied in relation to the human geography of the area clearly indicate that the socio-economic conditions of the region make it highly susceptible to any geomorphic hazard. This is due to factors such as a high population density in urban areas, a high density of dependent population (including children, elderly, and disabled individuals), a high rate of unemployment, and a low level of awareness regarding geomorphic hazards and measures to mitigate their risks. Thus, an accurate assessment on the susceptibility of the area to geomorphic hazards was found crucial for which an analysis of the geographical variability of geophysical and socio-economic factors has been necessary. From a geoenvironmental perspective, Kohima's vulnerability to landslides and associated geomorphic hazards, such as soil erosion, mass movement, flash floods in hills, and river line floods in downstream areas, has been increasing due to a combination of external factors like frequent seismic activities and heavy rainfall, as well as anthropogenic activities such as unplanned rapid urban growth, traditional shifting cultivation practices, and infrastructural development on unstable slopes. In order to address this significant environmental issue, it is imperative to undertake scientific and secure development initiatives which applies to all levels, including government, community, and individual. The research seeks to give comprehensive insights into the geographical knowledge of Kohima district, including the strategies to address and approaches that can be adopted to subjects related to geomorphological and environmental dangers, as well as the potential initiatives for disaster mitigation and management concerning the region.

- The geospatial analysis of the historical earthquake database in Kohima district and its surrounding area indicates that the region consistently experiences an active seismotectonic process, with an average of 27 events per year. Out of these events, 76% (20 events) are classified as microearthquakes (1-3 magnitude) to minor earthquakes (3-4 magnitude), which are typically attributed to local tectonic movements.
- The occurrence of microearthquake tremors is a significant worry for the local population due to the occurrence of various geostructural hazards including as land creeping, land fissuring, land subsidence, landslides, and slope failures. These hazards can result in economic losses and, in some cases, loss of life. To prevent or reduce these losses, a micro-minor earthquake hazard zone map has been created for the Kohima district.
- The map identifies four zones: an extreme hazard zone, a very high hazard zone, a high hazard zone, and a moderate hazard zone. The extreme hazard zone includes areas with more than 12 seismic events per 10km2 grid and the most stressed geophysical setup. The very high hazard zone includes areas with 8-12 seismic events per 10km2 grid and a very high stressed geophysical setup. The high hazard zone includes areas with 4-8 seismic events per 10km2 grid and a fragile geophysical

setup. The moderate hazard zone includes areas with 1-4 seismic events per 10km2 grid and a moderately stressed geophysical setup.

- The study also found that unplanned urbanization, along with infrastructure development in urban and suburban areas are the primary human-induced factors contributing to the high rate of erosion and soil loss. On the other hand, the natural causes of this phenomenon include the presence of young and highly erodible rock formations, fragmented reshaping of the landscape, and high-intensity rainfall. Any abrupt alteration in any of the aforementioned human-caused and natural variables would inevitably result in a rapid increase in erosion and loss of soil.
- The RUSLE model's output results indicate that the rainfall erosivity factor (RE) falls within the range of 648.12–1294.15 MJ mm/ha/h/year. The soil erodibility factor varies from a minimum of 0.10 to a maximum of 0.41 across the 15 existing soil classes. The ER factor values range from 0.01 to 0.04. The slope steepness (LS) factor values range from 0 to 1.22. The cover management (CM) factor values vary from a minimum of 0.0 in dense forest areas to a maximum of 1.80 in buildup areas. The conservation practice (CP) value ranges from 0.1 to 1.0, depending on the land use/cover pattern in the study region. The combined effects of these erosion and soil loss components lead to a much higher average erosion rate (about 9 t/ha/year) compared to the threshold value for soil erosion (less than 10 t/ha/year). The number varies between 0 and 92.18 metric tons per hectare per year.
- Consequently, the rapid erosion has been causing various geomorphic hazards in the area, including mass movement, debris fall, and landslides. This has had a negative impact on infrastructure, agricultural land, communities, rural livelihoods, natural resources, and the wildlife habitat. In order to reduce the significant erosion rate and its related geomorphic risks, it is crucial to enhance the CP factor or conservation measures at the governmental, community, and individual levels. Failure to promptly implement these essential measures may result in exacerbating ecological and social consequences.
- Owing to the district's vulnerability to landslide, a landslide hazard zonation map has been produced by using geospatial analysis of the AHP landslide study model. The research region was divided into five landslide danger zones based on the combined effects of existing elements that cause landslides. The landslide danger zones are categorized as low, moderate, high, very high, and extreme. Moreover, these zones

have been confirmed by on-site verification and address the locations most impacted by landslides in urban regions, rural areas, and along roads.

- In order to address the region's vulnerability to flash floods, the current study has created a map of flash flood hazard zones in the area. The map identifies three primary zones of flood danger: low, moderate to high, and high to very high flood hazard zones. Zones with high to very high elevation strike ridge regions (1600m-2950m) that are followed by a dense network of first-order streams with steep to very steep slope gradients (44º-80º) have been identified as locations with extremely low risk of flooding. This zone comprises approximately 17% (166.42 km2) of the district's total area. Areas with elevations ranging from 700m to 1200m, characterized by moderate to high slope gradients (20º-40º), such as second to third-order river valleys, midlevel river terraces, foothill zones, and downslope terrain, have been recognized as zones with a moderate to high risk for flooding. This zone encompasses around 37% (362.22 km2) of the district's total area. The primary geomorphic characteristics in this area include river bank erosion, slumps, landfall, and debris flow. The flood hazard is particularly high in the alluvial plain region in the northeast part, the piedmont zone, fluvial fans, and young low-level river terrace land along valleys. These areas, which include third to sixth-order river valleys and areas with rolling to gentle slope gradients (10º-20º), have been identified as highly susceptible to flooding. This zone encompasses approximately 18% (176.21 km2) of the district's total area.
- The study found that the region is experiencing significant environmental degradation. This degradation is occurring due to various factors: geophysically, such as frequent seismic events (27 per year), active tectonics, unstable geology, and changes in landforms and terrain; ecologically, including the loss of forest land and habitats at a rate of 5.91 km^2 or 0.60% annually, as well as the expansion of built-up areas and agricultural land at a rate of 2.73 km^2 or 0.28% annually, and 2.69 km^2 or 0.27% respectively. Additionally, there is an increase in waste land area at a rate of 0.49 km^2 or 0.05% annually.
- Climatologically, the district is experiencing rising temperatures at a rate of 0.13°C per year, a decrease in annual rainfall at a rate of 9.55 cm per year, an increase in extreme rainfall events and floods at a rate of 3 events per year, and a decrease in rainy days at a rate of 2 days per year.

- Additionally, the study suggests that environmental degradation and climate change are intensifying as elevations increase. As a result, the existing climatic zones, which include humid tropical, humid subtropical, humid temperate, and humid sub-temperate regions, are shifting towards higher altitudes at an average rate of 175 meters per year.
- Due to the impact of human-induced climate change, which is causing the region to experience a higher rate of climate change compared to the global average, The spatiotemporal analysis of monsoon hazard events in 1997 and 2022 revealed that the occurrence of hydrological hazards during the monsoon season varies from a minimum of 0.16% per year (1 event) for cloud bursts to a maximum of 2.58% per year (3 events) for landslides. Meanwhile, the occurrence of floods, land creeping, and land subsidence has been increasing at rates of 1.84% per year (2 events), 2.26% per year (2 events), and 2.58% per year (2 events) respectively. Consequently, the size of the extremely dangerous zone has been growing at a pace of 1.68% each year. This is a significant environmental problem for the sustainable socioeconomic development of the region. It is necessary to address this issue in order to reduce the increasing risk of monsoon-related hazards.
- The current study is thought to serve as a decision support system (DSS) for implementing scientific land use patterns and sustainable developmental planning, with a specific focus on considering the vulnerability to earthquakes, soil erosion, landslides, flash floods, climate change and land use changes.
- The study aims to contribute valuable insights to the field of geomorphological hazards and their mitigation and management in a specific region in Nagaland. The study will have a growing impact on enhancing applied research through the use of cutting-edge approaches and will emphasize the importance of such studies for achieving sustainable development. This will offer a comprehensive range of current geographical data, facilitating precise decision-making.
- The study will contribute to the existing knowledge in the fields of mountain environment geography, applied geomorphology, environmental geomorphology, hazards, and disaster mitigation and management. The study's findings will be valuable to several research communities, including geographers, geomorphologists, geologists, hydrologists, meteorologists, ecologists, and environmental scientists, for future research purposes. The project will present a comprehensive plan for reducing

and controlling geo-hazards, providing valuable guidance for policymakers and decision-makers.

- Disaster management is a complex process that involves four key elements: prevention, readiness, response/relief, and rehabilitation. The United Nations International Strategy for Disaster Reduction (UNISDR) emphasizes the importance of prevention, which involves proactive measures to prevent or reduce potential negative outcomes. Preparedness measures aim to anticipate and alleviate the consequences of both natural and man-made catastrophes, with the goal of reducing the impact on susceptible individuals.
- Response and relief efforts prioritize immediate and temporary needs, such as providing temporary shelter and access to water resources. Rehabilitation activities involve the restoration of infrastructure, healthcare services, and the implementation of rehabilitation development initiatives. Measures and procedures are put in place to avoid or mitigate future disasters. India has comprehensive and varied disaster management regulations, including the Legal and Institutional Framework, which establishes the National Disaster Management Authority (NDMA), State Disaster Management Authorities (SDMAs), and District Disaster Management Authorities (DDMAs).
- India's disaster management system is distinguished by a multi-tiered, multi-agency approach, guaranteeing effective disaster response and relief operations at the national, state, and district levels. The National Disaster Management Authority (NDMA) formulates policies, plans, and guidelines for managing disasters, in collaboration with other government agencies and organizations. The National Disaster Response Force (NDRF) offers disaster response and aid, while the National Disaster Management Plan (NDMP) delineates precise strategies for reducing and managing catastrophes at the national, state, and district levels.
- The Ministry of Home Affairs oversees the coordination of all disaster management efforts in the country, with various ministries and departments having primary and secondary responsibilities in disaster management. The Emergency Operations Centre (EOC) operates continuously, 24/7, to support the CRC. The Contingency Action Plan (CAP) is an all-encompassing national policy created to effectively handle natural calamities, incorporating state relief manuals and financing channels.
- In Nagaland, disaster management is holistic, focusing on all aspects of crisis response. The Nagaland State Disaster Management Authority (NSDMA) was

founded in January 2011 with support from the Government of India and the United Nations Development Programme's Disaster Risk Reduction Project (GoI-UNDP DRR Project). The NDMP was published in 2012, focusing on utilizing local resources to enhance the effectiveness and timeliness of disaster response.

- The Nagaland State Disaster Management Plan (NSDMP) aims to achieve several objectives, including identifying and evaluating vulnerabilities, developing measures to prevent and mitigate disasters, defining stakeholder roles, enhancing capabilities, implementing a structured Management Information System, promoting Indigenous Knowledge, raising awareness and sharing information, integrating capacity building, securing sufficient funding and resources, fostering community involvement, and reinforcing policy through legal measures.
- The State response Plan in Nagaland, India, offers directives for authorities, agencies, and organizations to coordinate an initial reaction to catastrophes. The strategy entails the issuance of directives by the State Emergency Operations Centre (SEOC), State Disaster Management Authority (SDMA), State Executive Committee (SEC), and other pertinent entities. The plan includes specific actions at the district level, such as the activation of the District Emergency Operations Centre (DEOC) upon receiving information about a disaster. The DEOC is responsible for issuing alerts and warnings, sending reports to the National Emergency Operation Center (NEOC) and Ministry of Home Affairs (MHA), organizing State Executive Committee meetings, and coordinating response efforts.
- Community members serve as initial responders in unforeseen calamities, with the assistance of law enforcement, State Disaster Response Forces (SDRFs), firefighting personnel, and medical services. International aid and post-mission debriefing evaluate the effectiveness of the reaction and suggest modifications to the strategy. The primary responsibility of state governments is to offer assistance to those affected by disasters, guaranteeing their safety, security, and overall welfare by providing essential resources such as food, water, shelter, clothes, and medical attention.
- The District Disaster Management Plan (DDMP) for Kohima district aims to mitigate the probability of disasters, enhance readiness, build a comprehensive system for responding to disasters, and accelerate the recovery and restoration process for impacted populations. The District Emergency Operations Centre (DEOC) functions as the primary control hub during crises.

- Non-Governmental Organizations (NGOs) are essential during times of crisis, but the degree of community knowledge and involvement in disaster management appears to be quite low. The Nagaland Voluntary Health Association (NVHA), the Eleutheros Christian Society (ECS), the Indian Red Cross, Lions Club Dimapur, Royal Club Kohima, Classic Club Kohima, and Rotary Club Kohima are prominent NGOs and non-profit organizations in Kohima.
- The findings indicate that the overall level of knowledge differs significantly throughout the district's six administrative divisions, based on their social, educational, cultural, demographic, and economic backgrounds where Kohima Sadar, one of the six divisions of the district, has a high degree of knowledge regarding geomorphic dangers. It represents 48% of the population in the subdivision. The subdivisions of Kezocha and Jakhama have achieved good levels of awareness, with 37% and 46% of their respective populations being represented. The level of awareness in Chiephobozou and Sechu Zubza sub divisions is poor, with 42% and 39% of the population respectively being represented. In contrast, Botsa sub division has a very poor level of awareness regarding geomorphic hazards and their risks, with 55% of the subdivision being represented.
- Infrastructure limitations, particularly in terms of road networks, hinder transportation and cause delays in emergency services delivery. Poor communication networks and frequent power outages during rain and thunderstorms create obstacles in the efficient operation of management. Inadequate urban planning and non-compliance with construction rules can also be attributed to a lack of information, limited awareness, or ignorance among the community.
- Collaboration between government agencies is crucial for effective disaster management in Kohima. Interagency communication difficulties arise due to differing protocols and systems, leading to misunderstandings and delays. Information silos may occur, leading to redundant work or deficiencies in the answer. Poor interagency cooperation in disaster management can be attributed to overlapping tasks, authority conflicts, uneven standard operating procedures (SOPs), and training discrepancies.
- Delay in providing assistance and rescue can be attributed to issues such as inadequate transportation, susceptibility to topographic challenges, insufficient coordination, and a lack of training. The National Disaster Management Authority (NDMA) and District Disaster Management Agency (DDMA) are commendable for

their efforts in disaster management, but there is much potential for development with more support from both the government and the general public.

- Inadequate instruction and training for psychological conditions are also significant issues. The strategies and regulations of disaster management currently do not adequately address the need for psychological care, and the community is unwilling to accept such treatment due to the stigma surrounding mental health.
- Flawed developmental plans, lack of informed decision-making, and lack of scientific and technological knowledge behind road widening, deforestation, and settlement expansion make Kohima more susceptible to the detrimental consequences of such activities. A lack of awareness of the specific requirements and preferences of the local community is another challenge.
- Inadequate rehabilitation endeavours in Kohima may be attributed to factors such as insufficient infrastructure, inadequate transportation, ineffective communication, and poor coordination. Insufficient community involvement is a significant obstacle in disaster management, as authorities often take unilateral action without providing adequate information, leaving victims to bear the consequences alone. Climate change is the primary issue of greatest concern, with increased temperature, drought days, severe rainfall, and shifts in climatic zones.
- This study examines four categories of geomorphological hazards: seismic activity, soil erosion, mass movements, and sudden floods, as well as the influence of hydrometeorological variables on land degradation. In order to effectively handle and reduce these risks, a set of techniques has been established.
    i. Identification of Hazard-Prone Areas: Hazard zoning maps are essential for implementing hazard reduction strategies. Hazard maps are created by conducting a comprehensive analysis of hazards associated with various cause variables and actual hazardous occurrences identified during field surveys. Hazard maps are solely beneficial if they are created at a dimension that is suitable for pragmatic implementation.
    ii. Assessment of Potential Hazards: It is necessary to have a thorough depiction of the geographical features of an area, including human habitations, vital infrastructures, roadways, and bridges. Demographic visualizations can provide insights into the spatial distribution and population density of a certain geographic area. These visualizations can assist identify vulnerable

components, assess the precise and overall risks associated with a hazard, and estimate potential economic damage if the hazard occurs as expected.

iii. Hazards Preparedness Plan: A hazards preparedness plan is a systematic arrangement of components that outlines a timetable for evaluating the likelihood of an event happening at a particular place within a defined period. It also involves implementing strategies to minimize the intensity and frequency of hazards, providing education on the characteristics, origins, and impacts of the hazard, and considering the probable effects on both natural ecosystems and the socioeconomic fabric of society.

iv. Legislation and regulations are necessary to regulate and reduce risks associated with hazards. Public policy for hazard management involves creating laws and rules that ban and limit growth in areas that are known to be at risk. An optimal approach to tackle the issue would entail implementing multiple deterrents, such as refraining from providing government aid for infrastructure development in regions prone to risks, restricting access to bank funding, withholding or removing essential amenities or facilities, and denying insurance coverage for perils associated with high-risk locations.

- Sustainable development may enhance the quality of life in a society by ensuring a balanced and efficient interaction between economic, socio-political, and ecological factors. For a community's growth, it is crucial to have a political system that promotes citizen involvement in planning and decision-making, an economic system that is self-sufficient and has sustainable productive capacities, and a social system that fosters cooperation and collaboration. It is essential to strike a balance between social sustainability and the occurrence of hazard-related disasters. This requires taking into account the conflicting requirements of citizens living in high-risk locations and homeowners in ecologically fragile regions.
- The economic well-being of a community is strongly influenced by its ability to withstand disasters. The primary goals of community disaster recovery are to maintain current businesses, promote new growth, and assure the sustainable reconstruction of companies. Ensuring the resilience of local companies and economic infrastructure is essential for the long-term viability of the economy. Environmental sustainability ensures the preservation of natural systems and prevents deterioration of biological and physical systems.

- It is crucial for planners and policymakers to establish a strong connection between hazard reduction and sustainable development, particularly in high-risk areas experiencing urban expansion and development. Hazard mitigation approaches facilitate the attainment of social welfare, environmental conservation, and economic progress in communities. Implementing risk mitigation planning techniques can result in enduring advantages and favourable transformation.
- To enhance disaster management in Kohima district and Nagaland, it is advised to establish a dedicated institution that specifically focuses on mitigation and management. This institution should gather information from various sources, create databases, identify effective techniques, develop educational modules, offer value-added courses, provide postgraduate and doctorate programs, serve as a platform for public policy discussions, maintain high standards of training and education, and establish a comprehensive directory of qualified volunteers from non-governmental organizations (NGOs) across the country.
- In addition, it is crucial to prioritize healthcare services for individuals affected by disasters. This can be achieved by establishing a network of laboratories in high-risk areas to conduct tests for infections and diseases, monitor outbreaks, and offer professional counselling to address psychological issues. It is imperative to include social scientists and psychologists in this undertaking.
- Government restrictions should be enacted to forbid or limit the development and use of places that have been recognized as hazardous. This might entail the suspension of government assistance for infrastructure development, restricted availability of essential commodities, and absence of insurance coverage. In addition, the government might utilize its power of compulsory acquisition to obtain areas for other land purposes.
- In order to identify between essential and ordinary frameworks, it is advisable to distinguish between vital structures and usual ones. It is essential to prioritize the establishment of regulations, the enforcement of bye-laws, and the assessment of hazards associated with urban buildings and structures. Furthermore, it is crucial to give priority to the implementation of micro-zonation in important urban areas.
- Ultimately, these suggestions seek to enhance disaster management in Kohima district and Nagaland by establishing a dedicated organization, enacting legislative measures, and giving priority to the execution of essential and standardized frameworks.

Plates

Plate 1: Upstream of Dzuna ru watershed, Kohima, Nagaland (unstressed geo-ecology)

Plate 2: Downstream of Dzuna ru watershed, Kohima, Nagaland (unstressed geo-ecology) bearing a confluence depicting the presence of shale stones and rounded sandstones

Plate 3: Spring found in the mid-stream of Charcha ru, Kohima, Nagaland which comes under the least stressed ecology

Plate 4: A large portion of the Charcha ru watershed environment under the practice of terrace cultivation

Plate 5: Evidence of Flash flood downstream of Charcha ru during heavy monsoon season

Plate 6: The infamous Sano ru landslide due to the presence of a fault accompanied by heavy monsoonal rains. This watershed is categorised under the highly stressed ecology

Plate 7: The highly stressed ecology watershed of Sano ru during the month of August,2018 when the district experienced one of the heaviest annual rainfalls.

Plate 8: The reconstructed Sano ru bridge which experienced heavy devastation due to landslide and flash floods

Plate 9: An alternate view of the reconstructed Sano ru bridge and the retaining walls along the river.

Plate 10: The moderately stressed Zachar ru where terrace cultivation is widely practiced which has proven to combat the land failure the area is prone to.

Plate 11: Rockfall zone along the NH 29 passing through the Zubza circle of Kohima district.

Plate 12: A subsidence zone along the Mereima village resulting in cracks and fissures in the nearby constructed buildings and roads

Plate 13: Massive road cutting along the NH-29 (Zubza) causing numerous landslides and rockfalls

Plate 14: The southern stretch of NH 29 (Phesama) upslope evident of land failure

Plate 15: Downslope of the southern stretch of NH 29 (Phesama) indicating land creeping.

Plate 16: Retaining walls built along the highway passing through Phesama village to combat the subsidence and land creeping

Plate 17: Bore wells found in the famous Tinpati landslide which further explains the vulnerability of the land

Plate 18: Quarrying practiced in the village of Kigwema under the Jakhama circle.

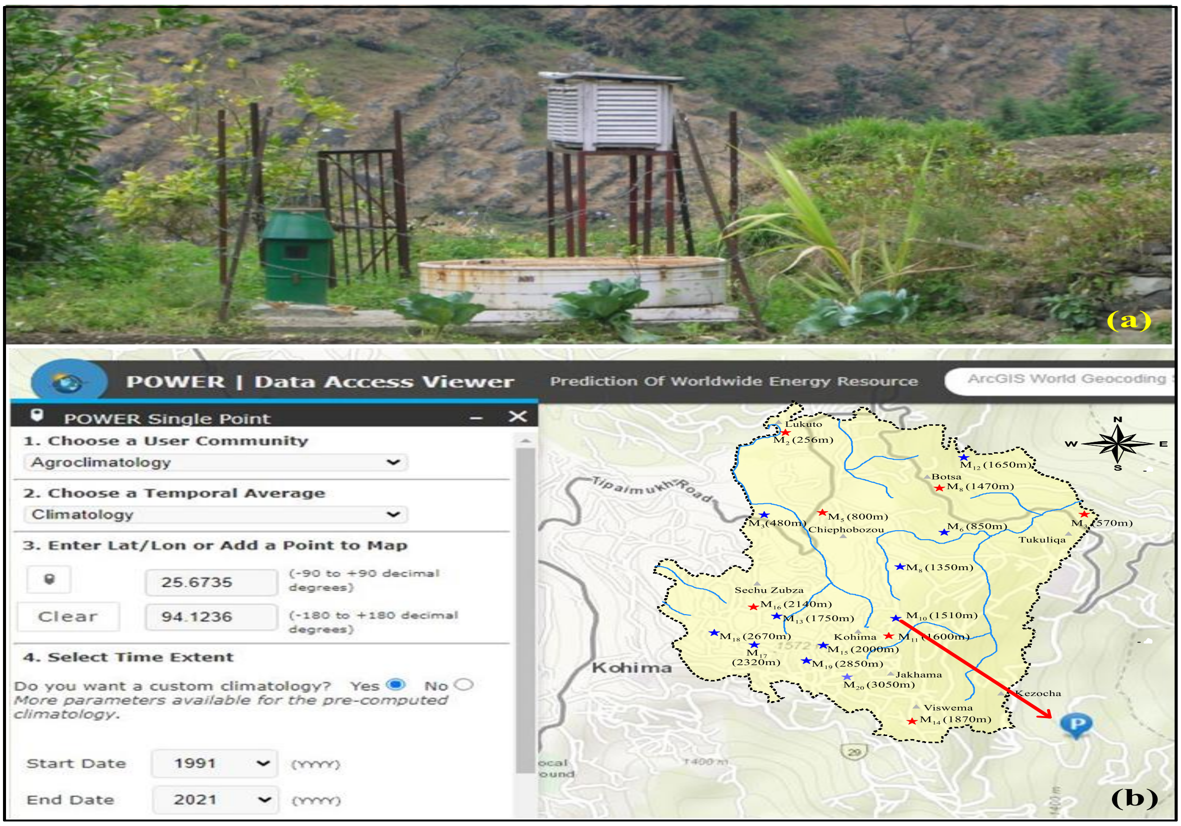


Plate 19: (a)- Meteorological apparatuses which are installed at each ground based metrological station. (b)- Website view of NASA- POWER geospatial climatic data showing the processer to download climatic data for selected locations.

Plate 20: A section of Kohima town with buildings constructed on very vulnerable sites indicating the hazardous state of the district.

Bibliography

Abdo, H., & Salloum, J. (2017). Spatial assessment of soil erosion in Alqer-daha basin, Syria. *Model Earth Syst Environ* 3:26

Adams, R.M., Fleming, R.A., Chang, C.C., McCarl, B.A., & Rosenzweig, C. (1995). A Reassessment of the Economic Effects of Global Climate Change on US Agriculture. *Climatic Change* 30, 147-167

Ader, T., Avouac, J., Lyon-Caen, H., Bollinger, L., Galetzka, J., Genrich, J., Thomas, M., Chanard, K., Sapkota, S.N., Liu-Zeng, J. (2012). Convergence rate across the Nepal Himalaya and interseismic coupling on the main Himalayan thrust: implications for seismic hazard. *J Geophys Res*. 117: B04403

Aggarwal, S., Rai, S., Thakur, P., & Emmer, A. (2017). Inventory and recently increasing GLOF susceptibility of glacial lakes in Sikkim, Eastern Himalaya. *Geomorphology*, *295*, 39–54. https://doi.org/10.1016/j.geomorph.2017.06.014

Agrawal, N., Gupta, L., Dixit, J., & Dash, S.K. (2023). Seismic risk assessment for the North Eastern Region of India by integrating seismic hazard and social vulnerability. *Sustainable and Resilient Infrastructure 8,* sup1, 102-132

Aier, I., Singh, M.P., Thong, G.T., & Ibotombi, S. (2012). Instability analyses of Merhulietsa slide, Kohima, Nagaland. *Nat. Hazards 60*, 1347–1363. https://doi.org/10.1007/s11069-011-9913-6

Aithal, B.H., M C, C. & G, N. (2019). Assessing land surface temperature and land use change through spatio-temporal analysis: a case study of select major cities of India. *Arab J Geosci* 12, 367. https://doi.org/10.1007/s12517-019-4547-1

Alemu, M.G., & Wubneh, M.A. (2023). Climate extreme indices analysis and spatiotemporal trend variation over Lake Tana sub-basin, upper Blue Nile basin, Ethiopia: under future climate change. *Arab J Geosci* 16: 660. https://doi.org/10.1007/s12517-023-11752-z

Ali, S., Sharma, M.R., & Maiteya, V.K. (1993). Climatic classification for building design in India.

Alimonti, G., & Mariani, L. (2023). Is the number of global natural disasters increasing? *Environmental Hazards,*1–17. https://doi.org/10.1080/17477891.2023.2239807Anand, G., Rahangdale, A., Mantri, S.S., Singh, S., & Kolathayar, S. (2022). Deterministic seismic hazard and landslide hazard zonation of Arunachal Pradesh. *J. Earth Syst. Sci. 131* **(**187) https://doi.org/10.1007/s12040-022-01942-w

Anbalagan, R., Kumar, R., Lakshmanan, K., Parida, S., & Neethu, S. (2015). Landslide hazard zonation mapping using frequency ratio and fuzzy logic approach, a case study of Lachung Valley, Sikkim. *Geoenviron Disasters* 2(6), 1–17, https://doi.org/10.1186/s40677-014-0009-y

Anbarasu, K., Sengupta, A., Gupta, S., Sharma, S.P., 2010. Mechanism of activation of the Lanta Khola landslide in Sikkim Himalayas. *Landslides 7*, 135–147, https://doi.org/10.1007/s10346-009-0193-0

Andreadis, K. M., Wing, O. E. J., Colven, E., Gleason, C. J., Bates, P. D., & Brown, C. M. (2022). Urbanizing the floodplain: global changes of imperviousness in flood-prone areas. *Environmental Research Letters*, 17(10), 104024. https://doi.org/10.1088/1748-9326/ac9197

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K., & Weesies, G. A. (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agric Ecosyst Environ 97*(1–3):295–308

Archit Sci Rev 36(1):31–34Fischer, G., Frohberg, K., Parry, M.L., & Rosenzweig, C. (1996). Impacts of potential climate change on global and regional food production and vulnerability. In: *Downing, TE (eds) NATO ASI Series, Climate Change and World Food Security, 137. Springer, Berlin*

Arekhi, S., Niazi, Y., & Kalteh, A.M. (2012). Soil erosion and sediment yield modeling using RS and GIStechniques:a case study. *Iran Arab J Geosci* 5(2):285-296. https://doi.org/10.1007/s12517-010-0220-4

Attri, S.D., Jyagi, A. (2010) Climate profile of India, Ministry of Earth Science, Indian Meteorological Department, Govt. of India

Ayala, A.I. (2002). Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47 (2): 107–124.

Baker, V.R. (1994). Geomorphological understanding of floods. Geomorphology 10 (1-4): pp. 139–156.

Balamurugan, G., Ramesh, V., & Touthang, M. (2016). Landslide susceptibility zonation mapping using frequency ratio and fuzzy gamma operator models in part of NH-39, Manipur, India. *Natural Hazards*, 84 (1), 465–488

Banerjee, R. (2010). Seismic Hazard zonation of Kachchh region using remote sensing (RS) and Geographic Information System (GIS), Department of Geology, Faculty of Science, University of Pune

Bansal, R.C. & Mathur, H.N. (1976). Landslides- the nightmare of roads. *Soil Conservation Digest, 4(1)*

Barman, B.K., & Rao, K.S. (2019). Landslide hazard susceptibility mapping of upper Tuirial watershed, Mizoram using Remote Sensing and GIS techniques. *International Journal of Research and Analytical Reviews* 6 (1), 1624–1630

Barman, D., Baruah, A., M, A. B., & Aggarwal, S. P. (2023). Hydrological-hydrodynamic nexus for predicting flood plain inundation: a case study in Pagladiya-Putimari catchment, India. *Arabian Journal of Geosciences,* 16(9), 526. https://doi.org/10.1007/s12517-023-11620-w

Bathurst, J. C., Iroumé, A., Cisneros, F., Fallas, J., Iturraspe, R., Novillo, M. G., Urciuolo, A., Bièvre, B. de, Borges, V. G., Coello, C., Cisneros, P., Gayoso, J., Miranda, M., & Ramírez, M. (2011). Forest impact on floods due to extreme rainfall and snowmelt in four Latin American environments 1: Field data analysis. *Journal of Hydrology*, 400(3–4), 281–291. https://doi.org/10.1016/j.jhydrol.2010.11.044

Belho, K., Rawat, M.S., & Rawat, P.K. (2023). GIS modelling to investigate environmental change and degradation in Kohima district of Nagaland, North East Hill region of India. *Environmental Monitoring and Assessmen*t. Accepted, in press

Belho, K., Rawat, M.S. & Rawat, P.K. (2024). Anthropogenic climate change accelerating monsoon hydrological hazards in Northeastern Himalayan region of India: geospatial approach. *Arab J Geosci* 17, 67. https://doi.org/10.1007/s12517-024-11871-1

Bell, R., Fort, M., Gotz, J., Bernsteiner, H., Andermann, C., Etzlstorfer, J., Posch, E., Gurung, N. and Gurung, S. (2018). Major geomorphic events and natural hazards during monsoonal precipitation 2018 in the Kali Gandaki valley, Nepal, Himalaya. Elsevier

Bentivoglio, R., Isufi, E., Jonkman, S.N., &Taormina, R. (2022). Deep learning methods for flood mapping: a review of existing applications and future research directions. *Hydrol. Earth Syst. Sci*. 26, 4345–4378. http://dx.doi.org/10.5194/hess-26-4345-2022

Bhandari, L.L., & Choudhary, L.R. (1975). Stratigraphic Analysis of Kadi and Kalol Formations, Cambay Basin, India. *Amer. Assoc. Petrol. Geol. Bull*., v.59, pp.856-871

Bhandari, R.K. (2002). Seismic microzonation. Chennai: Centre for Disaster Mitigation and Management, *Anna University*, 198 pp

Bhattacharjee, C.C. (1991). The ophiolites of northeast India — a subduction zone ophiolite complex of the Indo-Burman orogenic belt, Tectonophysics, Volume 191, Issues 3–4, Pages 213-222, ISSN 0040-1951, https://doi.org/10.1016/0040-1951(91)90057-Y. (https://www.sciencedirect.com/science/article/pii/004019519190057Y)Bloom 2012

Bhattacharjee, K., & Behera, B. (2017). Forest cover change and flood hazards in India. *Land Use Policy*, 67, 436–448. https://doi.org/10.1016/j.landusepol.2017.06.013

Bilwa, L.M., Yanthan, M.A., Madesh, P. & Hutti, B. (2015). Identification of Potential Landslide Hazard Zonation Mapping using Geoinformatics for Kohima Region, Nagaland, India International Journal of Innovative Science, Engineering & Technology, (IJISET) Vol. 2 (11).

Bloom, A. L. 1978: Geomorphology. A systematic analysis of late Cenozoic land forms. Englewood Cliffs, New Jersey: Prentice-Hall. xvii + 510 pp. £15.95: Ritter, D. F. 1978: Process geomorphology. Dubuque, Iowa: Wm C. Brown. xii + 603pp.

Brahim, B., Meshram, S.G., & Abdallah, D. (2020). Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). *Arab J Geosci* 13: 1153. https://doi.org/10.1007/s12517-020-06079-y

Brivio, P., Colombo, R., Maggi, M., & Tomasoni, R. (2002). Integration of remote sensing data and GIS for accurate mapping of flooded areas. *Int. J. Remote Sens*. 23 (3), 429–441

Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? Agriculture, Ecosystems & Environment, 104(1), 185–228. https://doi.org/10.1016/j.agee.2004.01.015.

Byers, A. C., Rounce, D. R., Shugar, D. H., Lala, J. M., Byers, E. A., & Regmi, D. (2019). A rockfall-induced glacial lake outburst flood, Upper Barun Valley, Nepal. *Landslides*, 16(3), 533–549. https://doi.org/10.1007/s10346-018-1079-9

CSIR-North Eastern Institute of Sceince and Technology, Jorhat, India

Cabrales, M.G.R. (2019). Exploitation of Resources. *In The Palgrave Encyclopedia of Global Security Studies*,1–3. Springer International Publishing. https://doi.org/10.1007/978-3-319-74336-3_332-1

Chakraborty, S., & Biswas, S. (2021). Simulation of flow at an ungauged river site based on HEC-HMS model for a mountainous river basin. *Arab J Geosci* 14(20):2080. https://doi.org/10.1007/s12517-021-08385-5

Challinor, A.J., Wheeler, T.R., Craufurd, P.Q., & Slingo, J.M. (2005). Simulation of the impact of high temperature stress on annual crop yields. *Agricultural and Forest Meteorology* 135: 180-189

Chan, D., &Wu, Q. (2015). Significant anthropogenic-induced changes of climate classes since 1950. *Scientific Reports*, 5(1), 13487. https://doi.org/10.1038/srep13487

Chen, Y., Khan, S., & Paydar, Z. (2010). To retire or expand a fuzzy GIS-based spatial multi-criteria evaluation framework for irrigated agriculture. *Irrig. Drain 59* (2), 174–188, https://doi.org/10.1002/ird.470

Chopra, B.R. (1977). Landslides and other mass movements along roads in Sikkim and North Bengal. *Bull. Int. As. Eng. Geol.* 16 (1), 162–166

Chorley, R.J., Schumm, S.A., and Sugden, D.E., (1985). Geomorphology, Methuen and Co.Ltd. London, New York.

Choudhury, M.K., & Nayak, T. (2003). Estimation of soil erosion in Sagar Lake catchment of Central India. *In: Proceedings of the inter- national conference on water and environment*, Dec15–18, 2003 Bhopal, India, pp 387–392

Coates, D.R. (1972). Environmental Geomorphology and landscape conservation, Vol. 1, Prior to 1900, benchmark paper in Geology, Dowden, Hutchinson and Ross, Stroudsbury.

Coleman, J.M. (1969). Brahmaputra River: Channel processes and sedimentation. *Sedimentary Geology*, *3*, 129–239.

Cooke, R.U. (1984). Geomorphological Hazards in Los Angeles: A Study of Slope and Sediment Problems in a Metropolitan city. The London Research Series in Geography. Vol. 7. xv+206. George Allen and Unwin.

Cruz, R.A.D. (1992). The determination of suitable upland agricultural areas using GIS technology. *Asian Pacific Remote Sen J.* 5:123–132

Dai, F., & Lee, C. (2002). Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology* 42 (3–4), 213–228, https://doi.org/10.1016/s0169-555x(01)00087-3

Darwin, R., & Kennedy, D. (2000). Economic effects of CO2 fertilization of crops: transforming changes in yield into changes in supply. *Environmental Modeling and Assessment* 5 (3):157–168

Darwin, R. (1999). A farmer's view of the Ricardian approach to measuring agricultural effects of climatic change. Climatic Change, 41: 371-411 watershed, Morocco. *Arab J Geosci* 16: 126. https://doi.org/10.1007/s12517-023-11206-6

Das, D. (2016). Changing climate and its impacts on Assam, Northeast India. Bandung: J*ournal of the Global South*, 2(1), 1–13. https://doi.org/10.1186/s40728-015-0028-4

Das, I., & Deka, S. (2021). Impact of Flood on the Socio-Economic Conditions in the Southern Part of Kamrup District, Assam. *Space and Culture, India*, 8(4), 106–119.https://doi.org/10.20896/saci.v8i4.665

Das R, Sharma ML, Wason HR, Gonzalez G, Chodhury D. (2019) A seismic moment magnitude scale. *Bull Seismol Soc Am*. 109(4):1542–1555.

Das, R., Menesis, C., & Urrutia, D. (2023) Regression relationships for conversion of body wave and surface wave magnitudes toward Das magnitude scale, M_{wg}. *Nat Hazards 117*, 365–380. https://doi.org/10.1007/s11069-023-05863-9

Das, T., Kothari, D. V., & Ojha, D. C. (1996). Bibliography on Desertification Soil Conservation and Environment.

Demek, J., Kalvoda, J., Kirchner, K. and Vilimek, V. (2006). Geomorphological Aspects of Natural Hazards and Risks in Czech Republic.

Demirci, A., & Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcek- mece Lake watershed, northwest Turkey. *Environ Earth Sci* 66(3):903–913

Deshpande, R.S. (2022). Disaster management in India: are we fully equipped? *Journal of Social and Economic Development*, 24(S1), 242–281. https://doi.org/10.1007/s40847-022-00225-w

Directorate of Census Operations Nagaland (2011): District Census Handbook, Kohima

Directorate of Geology and Mining (1996): Feasibility studies for groundwater development in the hilly terrain in and around Kohima town, Nagaland

Directorate of Soil and Water Conservation, Kohima, Nagaland: Meteorological data

District Census Handbook Kohima. (2011). Primary Census Abstract, Government of India, Nagaland.

Doerr, A.H. (1990). Fundamentals of physical geography (3rd Ed.), Iowa: Wm C. Browers Publishers

Douglas, I. (1993). The Tropics: Environments And Human Impacts Understood and Reinterpreted. Singapore Journal of Tropical Geography, 14(2), 103–122. https://doi.org/10.1111/j.1467-9493.1993.tb00044.x

Downs, P.W. & Booth, D.B. (2011). Geomorphology in Environmental Management; The Sage Handbook of Geomorphology: 81–101.

Dunne, T. and Leopold, L.B. (1978). Water in Environmental Planning. Freeman, New York, 818 p.

EM-DAT (Emergency Events Database). https://www.emdat.be/

Easterling, W.E. III., Crosson, P.R., Rosenberg, N.J., McKenny, M.S., Katz, L.A., & Lemon, K.M. (1993). Agricultural Impacts of and Responses to Climate Change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region. *Climatic Change* 24: 23-61

El-Swaify, S.A. (1997). Factors affecting soil erosion hazards and con- servation needs for tropical steep lands. *Soil Technol* 11(1):3–16

Enayat, A. (1985). Weakly compact cardinals in models of set theory. The Journal of Symbolic Logic, 50(2), 476–486.

Ettwein, V., Maslin, M. (2011) Physical Geography: Fundamentals of the physical environment, University of London

Faniran, A. and Jeje, L.K. (1983). Humid Tropical Geomorphology. Longman Groups Ltd., Ibadan.

Feizizadeh, B., & Blaschke, T. (2013). GIS-multicriteria decision analysis for landslide susceptibility mapping: comparing three methods for the Urmia Lake basin, Iran. *Nat Hazards* 65 (3), 2105–2128, https://doi. org/10.1007/s11069-012-0463-3

Fischer, Manfred. (2006). Spatial Analysis in Geography. 10.1007/3-540-35730-0_2.

Fischer, G.M., Shah, F., Tubello, J., van Veldhuizen. (2005). Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990-2080. *Philosophical Transactions of Royal SocietyB* 360: 2067-83

Furkumzuk, C., (2011): Integrated Watershed management in the Kiliki watershed of Zunheboto hills, Nagaland. Ph.D Thesis

Gabler, R.E., Petersen, J. F., Trapasso, L. M., (2007): Essentials of Physical Geography, Eight edition, Thomas Higher education, 10 Davis Drive, Belmont, USA

Gabler, R.E., Petersen, J. F., Trapasso, L. M., and Sack, D. (2009) Physical Geography, 9thedition, Brooks/Cole, Cengage learning

Ganasri, B.P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. *Geosci Front* 7(6):953–961. doi:10.1016/j.gsf.2015.10.007

Gares, P.A., Sherman, D.J., Nordstrom, K. (1994). Geomorphology and natural hazards. Geomorphology 10. Pg 1–18

Gelagy, H.S., & Minale, A.S. (2016). Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed, north-western Ethiopia. *Int Soil Water Conserv Res* 4(2):126–136

Geological Survey of India, Ministry of Mines, New Delhi, India

Geological Survey of India, Dimapur, Nagaland

Ghosh, C. (2013). Landslides induced damages due to recent Sikkim earthquake: strategies for geotechnical intervention. *In Proceedings of the international symposium on engineering under uncertainty: safety assessment and management (ISEUSAM-2012). Springer India* 1289–1298

Gole, C.V., & Chitale, S.V. (1966). Inland Delta Building Activity of Kosi River. *Journal of Hydraulic Engineering, 92,* 111-126.

Goudie, A. (1997). The Human Impact Reader- Readings and Case Studies, Blackwell Publishers, Oxford.

Goudie, A. (2001). The nature of environment (fourth edition). Blackwell Publishers Ltd. Oxford (UK).

Government of India (2022-23). Annual Report, *National Disaster Management Authority*

Government of India (2021-22). Annual Report, *National Disaster Management Authority*

Government of India (2020-21). Annual Report, *National Disaster Management Authority*

Government of India (2019-2020). Annual Report, *National Disaster Management Authority*

Government of India (2018-19). Annual Report, *National Disaster Management Authority*

Government of India, Contingency action Plan for Natural calamities, *unpublished report of Ministry of Agriculture, Department of Agriculture and Cooperation, N.D.M. Division*, New Delhi

Government of India. (2005). Disaster Management Act

Government of India (n.d.). Disaster Management in India, *Ministry of Home Affairs*

Government of India (2019): National Disaster Management Plan

Government of India (2009). National policy on Disaster Management, *Ministry of Home Affairs,* Government of India (2007). National Disaster Management Guidelines, Preparation of state Disaster Management Plans, *National Disaster Management Authority*

Government of India (2010). National Disaster Management Guidelines On Ensuring Disaster Resilient Construction of Buildings and Infrastructure financed through Banks and Other Lending Institution, *National Disaster Management Authority*

Government of India (2012). UNDP Disaster Risk Management Programme 2002-2009: Evaluation and Review of Lessons

Government of Nagaland (2019). District Disaster Management Plan Kohima

Government of Nagaland. (2012). Nagaland State Disaster Management Plan, *Nagaland State Disaster Management Authority, Home Department*

Government of Nagaland (2007): Nagaland State Disaster Management Rules, *Nagaland State Disaster Management Authority, Home Department*

Government of Nagaland. (n.d.). Standard Operating Procedure, *Nagaland State Disaster Management Authority, Home Department*

Government of India. (1999). Foreign Exchange Management Act (1999), *Directorate of Enforcement, Department of Revenue, Ministry of Finance*

Gregory, K. J., & Lewin, J. (2014). The Basics of Geomorphology: Key Concepts. SAGE Publications, Ltd. https://doi.org/10.4135/9781473909984

Groves, R.M., Fowler, F.J. Jr., Couper, M.P., Tourangeau, R., Singer, E., Lepkowski, J.M. (2004). Survey methodology. Wiley, New York

Gupta, H. K. (2018). Review: Reservoir triggered seismicity (RTS) at Koyna, India, over the past 50 yrs. *Bull. Seismol. Soc. Amer*. 108 2907–2918

Gupta, H. K. (2021). Understanding anthropogenic earthquakes. *Curr. Sci.* 120(9) 1415–1416

Gupta, H.K. (2023). Himalayan Seismic Belt, Seismic Gaps and Related Issues. *J Geol Soc India* 99, 1187–1190 https://doi.org/10.1007/s12594-023-2450-6

Gupta, A. (1993). The changing geomorphology of the humid tropics. Geomorphology, 7(1–3), pp. 165–186. https://doi.org/10.1016/0169-555X(93)90016-U

Gupta, M.C., Sharma, L.C., & Tamini, B.K. (2001). Manual on Natural Disaster management in India. New Delhi, *Department of agriculture & Cooperation, Government of India*. 204 pp

Gupta, L., Agrawal, N., Dixit, J., & Dutta, S. (2022). A GIS-based assessment of active tectonics from morphometric parameters and geomorphic indices of Assam Region, India. *Journal of Asian Earth Sciences X* 8, 100-115, https://doi.org/10.1016/J.JAESX.2022.100115

Haigh MJ, Rawat JS, Bisht HS (1988). Hydrological impact of deforestation in the central Himalaya. Proceedings of the Strbské Pleso Workshop, Czechoslovakia.

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1992). Analysis of landslide sites: Kilbury Road, Kumaun Himalaya, India. *Current Science* 62 (7), 518-522

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1993). Environmental influences on landslide activity: Almora Bypass, Kumaun Lesser Himalaya. *Natural Hazards* 8, 153-170

Haigh, M. J., Rawat J.S., Rawat, M.S., Bartariya, S.K. & Rai, S.P. (1995). Interaction between forest and landslide activity along new highways in Kumaun Himalaya. *Forest ecology and management*, 78 (173-189)

Haigh, M.J., Rawat, J.S., Bartarya, S.K., & Rawat, M.S. (1997). Environmental influences on landslide activity, Almora Bypass, Kumaon Lesser Himalaya. *In Contemporary Approaches to Indian Geography (ed. Rais Akhtar)*. APH Publishing Corporation, New Delhi, 243-262

Hamilton, L.S. (1987). What are the impacts of Himalayan deforestation on the Ganges-Brahmaputra lowland and delta? Assumptions and facts *Mountain Research and Development*7:256-263

Hansen, J.W., & Jones, J.W. (2000). Scaling-up crop models for climate variability applications. *Agricultural Systems* 65, 43-72 (2000)

He, L., Zhao, Y., & Njamba, B. (2024). Slope stability calculation based on sparrow search algorithm and Monte Carlo simulation. *Arab J Geosci* 17: 5. https://doi.org/10.1007/s12517-023-11799-y

Hibbeler, L. A. (2007). The role of Geomorphology in Natural Hazards Management. San Francisco State University.

Holtrop, J.F., & Keizer, J. (1970). Some Aspects of the Stratigraphy and Correlation of the Surma Basin Wells, East Pakistan. *ECAFE Mineral Resources Development Series*, 36, 143–154.ICIMOD.2015

Howden, M.J.F., Soussana, F., Tubiello, N., Chhetri, M., Dunlop, H., & Meinke. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19691-19696.

Humphrey, A.S. (2005). History Corner: Swot Analysis for Management Consulting [WWW Document]. *SRI Alumni Association*. URL. https://archive.sri.com/sites/ default/files/brochures/dec-05.pdf. accessed 1.23.2023.

Humphrey, A.S. (1974). Getting management commitment to planning: a new approach. Long. Range Plan. 7, 45–51. https://doi.org/10.1016/0024-6301(74)90078- 8.

Humphrey, A.S. (1969). Letter from Albert S. Humphrey to Birger Lie with the News that Joe McPherson "The Chair from Industry" from Dow Chemical Comes to Work for LRPS/TAPP. RFS & OJB got their wish.

IPCC (2022) Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

Iglesias, A., Garote, L., Flores, F., & Moneo, M. (2007b). Challenges to manage the risk of water scarcity and climate change in the Mediterranean. *Water Resources Management* 21:227-288

Iglesias, A., Rosenzweig, C., & Pereira, D. (2000). Prediction spatial impacts of climate in agriculture in Spain. *Global Environmental Change* 10:69–80

Indian Journal of Geomorphology (2010) Volume 15 (1 and 2). Indian Institute of Geomorphologists.

Indian Meteorological Department, Ministry of Earth Sciences, Government of India

International Committee of the Red Cross: https://www.icrc.org/en

Jain, S.K., Kumar, S., & Varghese, J. (1994). Estimation of soil erosion for a Himalayan watershed using GIS technique. *Geol. Soc. London* 151:217-220

James, L, A., Harden, J, J., Clague. 2013. Geomorphology of Human Disturbances, Climate Change, and Hazards. Academic Press. Pages 1-13.

Jibhakate, M., Timbadiya, S.V.P., & Patel, L.P. (2023). Multiparameter flood hazard, socioeconomic vulnerability and flood risk assessment for densely populated coastal city. *Journal of Environmental Management*, 344, 118405. https://doi.org/10.1016/j.jenvman.2023.118405

John, S.E., Rajimol, T.R., & Mohan, S.V. (2017). Environmental degradation of a tropical estuary due to human interferences—a case study from southern Kerala, SW India. *Arab J Geosci* 10: 352. https://doi.org/10.1007/s12517-017-3112-z

Journal of Indian Geomorphology (2013) Vol. 2. Indian Institute of Geomorphologists.

Kale, V.S. and Gupta, A. (2001): Introduction to Geomorphology. Orient Longman Limited. P. 256.

Kalvoda, J. (1996). The geodynamics of landforms hazard processes. Acta Univ. Carol., Geographica 31, 2, 7–32.

Kalwar, S.C., Sharma, M.L., Gurjar, R.D., Khandelwal M.K., and Wadhawan, S.K (2005). Geomorphology and Environmental Sustainability. Concept Publishing Company, New Delhi.

Kapur, A. (2009). On Disaster in India. Cambridge University Press India, Pvt. Ltd. New Delhi.

Karan, P.P. (1987). Bhutan: Development amid environmental and cultural preservation. Institute for the study of languages and culture of Asia and Africa

Kassa, M., & Meten, M. (2023). Slope stability analysis using kinematic, limit equilibrium, and finite element models at Dessie town, northern Ethiopia. *Arab J Geosci* 16: 675.https://doi.org/10.1007/s12517-023-11783-6

Katupotha, K. N. J. (2004). Geography Subject.Kayal, J.R., Baruah, S., Hazarika, D., & Das, A. (2022). Recent large and strong earthquakes in the eastern Himalayas: An appraisal on seismotectonic model. *Geological Journal* 57 (12), 4929–4938, https://doi.org/10.1002/gj.4576

Katz, R.W., & Brown, B.G. (1992). Extreme events in changing climate variability is more important than averages. *Climatic Change* 21, 289-302

Khan, A., Farah, H., & Khan, S. (2023). Comparative assessment of spatiotemporal variability in cryosphere and hydro-climatic regime of the Hunza, Astore and Shigar Basins (Hindukush-Karakoram–Himalaya Region) in Pakistan. *Arab J Geosci* 16: 350. https://doi.org/10.1007/s12517-023-11440-y

Khanifar, J. (2022). Modeling of soil thickness based on DEM derivatives calculated using different polynomials. *Arab J Geosci* 15, 655.https://doi.org/10.1007/s12517-022-09941-3

Khatsii, P. (2004). Urban multi- hazard risk analysis using GIS and Remote Sensing; A case study of landslide, earthquake and fire hazard in a part of Kohima town, India. ITC, The Netherlands and Indian Institue of Remote Sensing, Dehradun.

Kolat, C., Ulusay, R., & Suzen, M.L. (2012). Development of geotechnical microzonation model for Yenisehir (Bursa, Turkey) located at a seismically active region. *Eng. Geol.* 127, 36–53, https://doi.org/10.1016/j. enggeo.2011.12.014

Kouli, M., Soupios, P., & Vallianatos, F. (2009). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ Geol* 57(3):483–497

Kumar, D., Thakur, M., Dubey, C.S., & Shukla, D.P. (2017). Landslide susceptibility mapping & prediction using Support Vector Machine for Mandakini River Basin, Garhwal Himalaya, India. *Geomorphology* 295, 115–125, https://doi.org/10.1016/j.geomorph.2017.06.013

Kusi, K.K., Khattabi, A., Mhammdi, N. (2023). Evaluating the impacts of land use and climate changes on water ecosystem services in the Souss. *Arabian Journal of Geosciences, volume 16, issue 2, publication number 126.* 10.1007/s12517-023-11206-6

Lampert, A. (2019). Over-exploitation of natural resources is followed by inevitable declines in economic growth and discount rate. *Nature Communications*,10(1), 1419. https://doi.org/10.1038/s41467-019-09246-2

Lobell, D.B., & Burke, M.B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology* 150: 1443-1452

Lohe, S. (2014). Environmental management of degraded ecosystem in Phek district, Nagaland- A geomorphological approach. Ph.D. thesis

Lynn, P. (2008). The problem of nonresponse. In: deLeeuw E, Hox J, Dillman D (eds) The international handbook of survey methodology. Lawrence Erlbaum Associates, Mahwah, NJ, pp 35–55

Lynn, P. (2002). Sampling in human studies. In: Greenfield T (ed) Research methods for postgraduates, 2nd edn. Arnold, London, pp 195–202

Magnan, A. K., Pörtner, H.-O., Duvat, V. K. E., Garschagen, M., Guinder, V. A., Zommers, Z., Hoegh-Guldberg, O., & Gattuso, J.-P. (2021). Estimating the global risk of anthropogenic climate change. *Nature Climate Change*, 11(10), 879–885. https://doi.org/10.1038/s41558-021-01156-w

Mathew, J., Jha, V.K., & Rawat, G.S. (2007). Application of binary logistic regression analysis and its validation for landslide susceptibility mapping in part of Garhwal Himalaya, India. *Int. J. Remote Sens.* 28 (10), 2257– 2275, https://doi.org/10.1080/01431160600928583

Mathur, L.P., Evans, P. (1964). Oil in India: 2nd Int. Geol. Cong. New Delhi

Mearns, L.O., Rosenzweig, C., & Goldberg, R. (1997). Mean and variance change in climate scenarios: Methods, agricultural applications, and measures of uncertainty. *Climatic Change* 35: 367-396

Meliho, M., Khattabi. A., & Asinyo, J. (2021). Spatial modeling of flood susceptibility using machine learning algorithms. *Arab J Geosci* 14: 2243. https://doi.org/10.1007/s12517-021-08610-1

Meshram, S.G., Powar, P.L., & Singh, V.P. (2017). Modelling soil erosion from a watershed using cubic splines. *Arab J Geosci* 10:155–168. https://doi.org/10.1007/s12517-017-2908-1

Miller, R.W., & Donahue, R.L. (1990). *Soils: an introduction to soils and plant growth, 6th edn. Prentice Hall, Englewood Cliffs*

Mohanty, M. P., Mudgil, S., & Karmakar, S. (2020). Flood management in India: A focussed review on the current status and future challenges. *International Journal of Disaster Risk Reduction*,49, 101660. https://doi.org/10.1016/j.ijdrr.2020.101660

Moore, I.D., & Burch, G.J. (1986). Physical basis of the length slope factor in the Universal Soil Loss Equation. *Soil Sci Soc Am* 50:1294–1298

Mohallel, S.A., & Gomaa, M.A. (2017). Studying the impacts of groundwater evolution on the environment, west Qena city, Egypt. *Arab J Geosci* 10: 372. https://doi.org/10.1007/s12517-017-3151-5

Mohapatra, J.B., Sahu, A.P., & Rout, B. (2021). Analysis of long-term rainfall patterns using high-resolution atmospheric data over Odisha. *Arab J Geosci* 14: 2223. https://doi.org/10.1007/s12517-021-08528-8

Mosley, M. P., & O'Loughlin, C. (1980). Slopes and slope processes. *Progress in Physical Geography: Earth and Environment,* 4(1), 97-106. https://doi.org/10.1177/030913338000400107

Mostafa, S.I., & Mohamed, A.E. (2021). A Seismotectonic studies in Aswan area, Egypt. *Arab J Geosci* 14: 2210. https://doi.org/10.1007/s12517-021-08608-9

NIDM (National Institute of Disaster Management). https://nidm.gov.in/

Nag, Pritvish, Kumra, V.K. and Singh, Jagadish (1997). Geography and Environment; Volume one, National Issues. Concept Publishing Company, New Delhi.National Disaster Risk Reduction Portal (Nagaland).

Nagaland GIS and Remote Sensing Centre (NGISRSC), Kohima, Nagaland, 797001

Nakata T (1972) Geomorphic History and Crustal Movements of the Foot-hills of the Himalaya. *Tohoku University Science Reports, 7th Series, Japan* 22: 39–177.

Orimoloye, I. R., Belle, J. A., & Ololade, O.O. (2021). Exploring the emerging evolution trends of disaster risk reduction research: a global scenario. *International Journal of Environmental Science andTechnology,* 18(3), 673–690. https://doi.org/10.1007/s13762-020-02847-1

Oya, M. (2001). Applied Geomorphology for Mitigation of Natural Hazards (Vol. 15). Springer Netherlands. https://doi.org/10.1007/978-94-010-0961-4.

Pachauri, A., & Pant, M. (1992). Landslide hazard mapping based on geological attributes. *Eng. Geol.* 32 (1–2), 81–100, https://doi.org/10.1016/0013-7952(92)90020-y

Pal, I., Nath, S.K., Shukla, K., Pal, D.K., Raj, A., Thingbaijam, K.K.S., & Bansal, B.K. (2008). Earthquake hazard zonation of Sikkim Himalaya using a GIS platform. *Nat Hazards* 45 (3), 333–377, https://doi.org/10.1007/s1106 9-007-9173-7

Pannizza, M. (1987). Geomorphological hazard assessment and the analysis of geomorphological risk. In V.Gardiner (ed.) International Geomorphology 1986, pp. 225–229. Part I. New York: Wiley.

Parry, M.L., Fischer, C., Livermore, M., Rosenzweig, C., & Iglesias, A. (1999). Climate change and world food security: a new assessment. *Global Environmental Change* 9: S51–S67

Pimentel, D,, Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science* 267(5201):1117–1123

Pirazizy, A. A. (1992). Environmental Geography and Natural Hazards. *Concept's International Series in Environment*

Pirazizy, A.A. (1989). Impact of Construction Activities on Environmental Changes in Kashmir Himalayas, In I, Mohan, *Environmental Issues and Programmes*, New World Environment Series, Ashish, New Delhi

Porter, J.R., & Semenov, M.A. (2005). Crop responses to climatic variation. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360, 2021-2035.nge 35: 367-396

Pradeep, G.S., Krishnan, M.V.N., & Vijith, H. (2015). Identification of criti- cal soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. *Arab J Geosci* 8(6):3697–3711

Prakash, I. (1994). Disaster Management, Rasthra Prahari Prakashan, New Delhi

Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. *Geosci Front* 3(2):209–215

Rama, Rao. M.S.V. (1962). Soil conservation in India. *Indian Council of Agricultural Research*, New Delhi. Retrieved from http://krishi-kosh.egranth.ac.in/handle/1/2049015

Ramasamy, S.M., Gunasekaran, S., Saravanavel, J., Melwyn, J.R., Rajaperumal, R., Kathiravan, R., Palanivel, K., & Muthukumar, M. (2021). Geomorphology and Landslide Proneness of Kerala, India A Geospatial study. *Landslides 18*, 1245–1258, https://doi.org/10.1007/s10346-020-01562-9

Ramli, M.F., Yusof, N., Yusoff, M.K., Juahir, H., & Shafri, H.Z.M. (2010). Lineament mapping and its application in landslide hazard assessment: a review. *Bull Eng Geol Environ* 69, 215–233, https://doi.org/10.1007/ s10064-009-0255-5

Rawat, M. S. (2003). Pattern of headwater erosion in Animal Park catchment, Kumaon Himalaya.. *Nagaland University Research Journal (NURJ*), Vol. 1, p. 37-40. 25

Rawat, M. S. (2004). Geospatial information technology for development planning in Nagaland. In: *Economic Development in Nagaland: Prospects and Constraints* (eds. A. Sema, et. al.), N.V. Press, Kohima, p. 340-356

Rawat, M. S. (2011). *Environmental Geomorphology and Watershed Management*. Concept Publishing Company, New Delhi (ISBN-13:978-81-8069-758-6)

Rawat, M. S. (2013). Sustainable development in Nagaland through integrated watershed management: A case study from Kiliki River Basin. *International Journal of Development Studies and Research*, Vol. 2, 60-80

Rawat, M. S. (2017). Environmental management in the headwater catchments of Kiliki river, Nagaland, North East India. In Ecosystem Services of Headwater Catchments, Josef Kreceket. al., (eds). Springer (via Capital Book Pvt. Ltd, New Delhi), pp. 130–141.

Rawat, M. S., & Furkumzuk, C. (2013). Environmental management and sustainable development in the Kiliki watershed of Nagaland. *Indian Journal of Environmental Studies*, Vol. 01, (01), 26-42

Rawat, J.S., & Rawat, M.S. (1994). The Nana Kosi Watershed, Central Himalaya, India. Part-II: Human Impacts on Stream Runoff. *Mountain Research and Development*, 14:3, 255-260

Rawat, M. S., Rawat, J. S. and Haigh, M. J. (1992). Sediment discharge from a Himalayan pine forested headwater. In Environmental Regeneration in Headwaters. Josef Krecek and M. J. Haigh (eds.), Institute of Applied Ecology, Agricultural University of Prague, Czech Republic, 182-187.

Rawat, M. S., Rawat, J. S., & Haigh, M. J. (1995). Patterns of headwater sediment yield from Himalayan pine forest. *In: Hydrological Problems and Environmental Management in Highlands and Headwaters* (eds. Josef Krecek et al.), Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi, p. 364-393

Rawat, M. S., & Haigh, M. J. (1998) Rainy season runoff and sediment yields of forested and non-forested catchments in Kumaun Himalaya. In: *Proceedings of the 8th International Conference on Soil and Water Conservation: Challenges and Opportunities* (eds. L. S. Bhushan, I. P. Abrol and M. S. Ramamohan Rao). Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, Vol. II, p. 1458-1465

Rawat, M. S., Haigh, M. J. Krecek, J., & Rawat, J. S. (1999). Dissolved load of a Central Himalayan Forest headwater in an experimental catchment, India. *In: Biogeochemistry of Rivers in Tropical South and South East Asia.* (eds. Ittekkot, et. al.), Mitt. Geog. Palaont. Inst. Univ. Hamburg/SCOPE Sonderband Heft 82, Germany, Marz, p. 185-195

Rawat, P. K. (2011). Impacts of climate change and hydrological hazards on monsoon crop pattern in Lesser Himalaya: a watershed-based study. *International Journal of Disaster Risks Science*, Vol. 3 (2): 98–112

Rawat, P. K. (2014). GIS Development to monitor climate change and its geohydrological consequences on Non-monsoon crop pattern in Lesser Himalaya. *Int. J. Computers and Geosciences* 70: 80-95

Rawat, P. K., & Pant, B. (2023). Geoenvironmental GIS development to investigate Landslides and Slope Instability along Frontal zone of Central Himalaya. *International Journal of Natural Hazard Research*, Vol.3 (2), 196–204

Rawat, P. K., Pant, B., Pant, K.K., & Pant, P. (2021). Geospatial analysis of alarmingly increasing human-wildlife conflicts in Jim Corbett National Park's Ramnagar buffer zone: Ecological and socioeconomic perspectives. *International Journal of Geoheritage and Parks*. 10, 337–350. DOI: 10.2139/ssrn.3938066

Rawat, P. K., & Pant, C. C. (2016). Environmental Geoinformatics: Theory to Practice for Disaster Management, Lambert Academic Publishing, Saarbrücken Germany: 1–219

Rawat, P. K., Pant, C. C., & Bisht, S. (2017). Geospatial analysis of climate change and emerging flood disaster risk in fast urbanizing Himalayan foothill landscape. *International Journal of Geomatics, Natural Hazard and Risks*, 8(2): 418–447

Rawat, P. K., Tiwari, P.C., & Pant, C.C. (2011). Modeling of Stream Runoff and Sediment output for erosion hazard assessment in Lesser Himalaya; Need for sustainable land use plane using Remote Sensing and GIS: A case study. *Natural Hazards* 59:1277–1297

Rawat, P. K., Tiwari, P.C., Pant, C.C., Sharama, A.K., & Pant, P.D. (2011a). Spatial variability assessment of river-line floods and flash floods in Himalaya: A case study using GIS. *International journal of Disaster Prevention and Management* 12(2): 135-159

Rawat, P. K., Tiwari, P. C., & Pant, C. C. (2012). Geo-diversity and its hydrological response in relation to landslide susceptibility in Himalaya: A case study using GIS. *Int. J. of Georisk* 6(4): 229-251

Rawat, P. K., Tiwari, P. C., & Pant, C. C. (2012a). Geo-hydrological database modeling for integrated multiple hazard and risks assessment in Lesser Himalaya: a GIS based case study. *Int. J. Nat. Hazards* 62(3): 1233–1260

Rawat, P. K., Tiwari, P. C., & Pant, C.C. (2012b). Climate Change accelerating land use dynamic and its environmental and socio-economic risks in Himalaya: Mitigation through sustainable land use. *International Journal of Climate Change Strategy and Management*4(4):452-471

Reddy, R.K., Ramanaiah, Y.V., Kumari, A.K., & Subbiah, S. (Ed.) (2009). Natural hazards and Disasters Essays and Impact and management, *International Conference Volume.*

Department of Geography, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India

Renard, K.G., & Foster, G.R. (1983). Soil Conservation—Principles of ero- sion by water. *In: Dregne HE, Willis WO (eds) Dryland Agriculture. American Society of Agronomy, Soil Science Society of America, Madison, WI, USA*, pp 155–176

Rentschler, J., Avner, P., Marconcini, M., Su, R., Strano, E., Vousdoukas, M., & Hallegatte, S. (2023). Global evidence of rapid urban growth in flood zones since 1985. *Nature*, 622(7981), 87–92. https://doi.org/10.1038/s41586-023-06468-9

Reynolds, S.J., Rohli, R. V., Johnson, J. K., Waylen, P.R., Francek, M. A. (2015). Exploring Physical Geography. The McGraw hill companies, Inc. pp. 1-693

Rosenfeld, C. L. (1994). The geomorphological dimensions of natural disasters. Geomorphology, 10(1–4), 27–36. https://doi.org/10.1016/0169-555X(94)90006-X

Rosenzweig, C., & Parry, M.L. (1994). Potential impact of climate change on world food supply. *Nature* 367:133–138

Rudra, K. (2014). Changing river courses in the western part of the Ganga–Brahmaputra delta. *Geomorphology*, 227, 87–100. https://doi.org/10.1016/j.geomorph.2014.05.013

SAARC (South Asian Association for Regional Cooperation). https://www.saarc-sec.org/

Saaty, T.L. (1980). The analytic hierarchy process. McGraw-Hill, New York

Sadek, M., Li, X., & Mostafa, E. (2021). Monitoring flash flood hazard using modeling-based techniques and multi-source remotely sensed data: the case study of Ras Ghareb City, Egypt. *Arab J Geosci* 14: 2030. https://doi.org/10.1007/s12517-021-08341-3

Sally H. Potter, Peter V. Kreft, Petar Milojev, Chris Noble, Burrell Montz, Amandine Dhellemmes, Richard J. Woods, Sarah Gauden-Ing, (2018). The influence of impact-based severe weather warnings on risk perceptions and intended protective actions, *International Journal of Disaster Risk Reduction*, Volume 30, Part A, Pages 34-43, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2018.03.031.

Sapkota, S.N., Bollinger, L.K., Linger, Y., Tapponier, P., Gaudemer, Y., Tiwari, D. (2013). Primary surface ruptures of the great Himalayan earthquakes in 1934 and 1255. *Nature Geosci*. 6(2)152:7176

Satendra. (2001a). Disaster And Development; Silver Jubilee Issue of Employment news, Publication Division, *Ministry of Information and Broadcasting*, New Delhi

Satendra. (2001b). Dealing with Disaster, Dow to Earth, vol 9 No. 23, *Centre for Science and Environment*, New Delhi

Satendra. (2003). Disaster management in the Hills. *Concept Publishing Company,* New Delhi

Sattar, A., Goswami, A., Kulkarni, Anil. V., Emmer, A., Haritashya, U. K., Allen, S., Frey, H., & Huggel, C. (2021). Future Glacial Lake Outburst Flood (GLOF) hazard of the South Lhonak Lake, Sikkim Himalaya. *Geomorphology,* 388, 107783. https://doi.org/10.1016/j.geomorph.2021.107783

Saxena, H. M. (1999). Environmental Geography (Vol. viii). Jaipur Rawat Publications c1999.

Schmidhuber, J., & Tubiello, F.N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19703-19708

Schlenker, W., Hanemann, W.M., & Fisher, A.C. (2006). The impact of global warming on US agriculture: An econometric analysis of optimal growing conditions. *Review of Economics and Statistics* 88, 113-125

Semenov, M.A., & Porter, J.R. (1995). Climatic variability and the modeling of crop yields. *Agricultural and Forest Meteorology* 73, 265-283 (1995)

Shahiri, P. A., Noori, M., Heydari, M., &Rashidi, M. (2016). Floodplain Zoning Simulation by Using HEC-RAS and CCHE2D Models in the Sungai Maka River. *Air, Soil and Water Research,* 9, ASWR.S36089. https://doi.org/10.4137/ASWR.S36089

Sharma, H.S (1991). Indian Geomorphology; Selected papers from the 2nd Conference of the Indian Institute of Geomorphologists on Environmental Geomorphology. Concept Publishing Company, New Delhi.

Simonett, D. S. (1967). Landslide distribution and earthquakes in the Bewani and Torricelli Mountains, New Guinea. Landform Studies from Australia and New Guinea (Ed by J. N. Jennings & J. A. Mabbutt), pp. 64-84. Cambridge University Press, Cambridge

Singh, S. (1991). Ecology. Prayag Pustak Bhawan

Singh, S. (1998). Geomorphology. Prayag Pustak Bhawan, 1998.

Singh, S. (2007). Geomorphology (Vol. iv). Prayag Pustak Bhawan, 2007.

Sing, S.K. (2006). Spatial variability in erosion in the Brahmaputra basin: causes and impacts. *Curr Sci* 90(9):1272–1276

Singh, S. (2019). Changing perspectives in Geomorphology. Journal of Indian Geomorphology, Volume 7

Sing, S. (2009). Environmental geography. Published by Prayag Pustak Bhawan 20-A, University Road, Allahabad

Slaymaker, O. (1996). Geomorphic Hazards. Wiley Chichester, pp. 1-7.

Slingo, J.M., Challinor, A.J., Hoskins, B.J., & Wheeler, T.R. (2005). Introduction: food crops in a changing climate. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360: 1983-1989

Srivastava, P., Singh, I.B., Sharma, M., & Singhvi, A.K. (2003). Luminescence chronometry and Late Quaternary geomorphic history of the Ganga Plain, India. *Palaeogeogr Palaeoclimat Palaeoeco* 197: 15–41

Srivastav, S.K., & Pandey, N. (2011). Search for provenance of Oligocene Barail Sandstones in and around Jotsoma, Kohima, Nagaland. *Journal of Geological Society of India* 77, 433-442

Srivastava,V., Nakhro, R., & Pandey, N. (2013): Geometry of mesoscopic folds in the vicinity of Disang and Piphima thrust in Kohima district, Nagaland

Starkel, H. (2004). Temporal clustering of extreme rainfall events in relief transformation. Journal Geological Society of India, pp. 64, 517–523.

Starkel, L. (1972a) The role of catastrophic rainfall in the shaping of the relief of the lower Himalaya (Darjeeling Hills), *Geographia Polonica*, 21: 103–160.

Starkel, L. (1972b) The modelling of monsoon areas of India as related to catastrophic rainfall, *Geographia Polonica*, 23: 151–173.

Statistical handbook of Nagaland (2011). Directorate of Economics and Statistics, Government of Nagaland, Kohima

Stott, P. A., Gillett, N. P., Hegerl, G. C., Karoly, D. J., Stone, D. A., Zhang, X., & Zwiers, F. (2010). Detection and attribution of climate change: a regional perspective. *WIREs Climate Change*, 1(2), 192–211. https://doi.org/10.1002/wcc.34

Strahler, A.N. (1956). Quantitative slope analysis. *Bull. Geol. Soc. Am.*, 67: 571-596

Strahler, A., (2013). Introducing physical geography. 6th edition. John wileys and Sons, Inc.pp 1-661

Strahler, A.N., Strahler, A.H., (1978). Modern Physical geography. John Wileys and Sons, Inc pp.1-532

Summerfield, M.A. (2005). The changing landscape of geomorphology. Earth Surface Processes, Landforms, 30, 729-781.

Sundriyal, Y., Vipin, K., Neha, C., Sameek, K., Rahul, R., & Mohit, K. P. (2023). Brief communication: The northwest Himalaya towns slipping towards potential disaster. *Nat. Hazards Earth Syst. Sci.*, 23, 1425–1431

Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, 10(1), 13768. https://doi.org/10.1038/s41598-020-70816-2

Tao, F.L., Yokozawa, M., Xu, Y.L., Hayashi, Y., & Zhang, Z. (2006). Climate changes and trends in phenology and yields of field crops in China, 1981-2000. *Agricultural and Forest Meteorology* 138, 82-92

Thakur, V.C. (2004). Active tectonics of Himalayan Frontal Thrust and seismic hazard to Ganga Plain. *Curr. Sci.* 86:1554–1558

Thigale, S.S. & Khandge, A. (2000). Landslides in Western Ghats of Maharashtra. In: *Contributions to environmental geoscience*, ed. A.M. Pathan and S.S. Thigale. New Delhi: Aravali Books Intern. 161-174

Thingo, V. (1994). Terrain evaluation of Kohima District, Nagaland, with special reference to Geomorphology. PhD Thesis. Gauhati University.

Thornbury, W. D. (1954). Principles of Geomorphology. Soil Science, 78(2), 157. https://doi.org/10.1097/00010694-195408000-00023.

Thornbury, W. D., (1968). Geomorphology, Wiley Publishers.

Thornbury, W.D. (1997). Principles of Geomorphology, New Age International (P) Limited Publishers

Tiwari, P. (2008). Land use changes in Himalaya and their impacts on environment, society and economy: A study of the Lake Region in Kumaon Himalaya, India. *Advances in Atmospheric Sciences*, 25(6), 1029–1042. https://doi.org/10.1007/s00376-008-1029-x

Tollan, A. (2002). Land-use change and floods: what do we need most, research or management? *Water Science and Technology*, 45(8), 183–190. https://doi.org/10.2166/wst.2002.0176

Tripathi RP, Singh HP (1993) Soil erosion and conservation. New Age International Publishers, New Delhi, p 10

USDA (1981). Rainfall erosion losses from cropland east of the rocky mountain. Handbook no. 282. US Department of Agriculture, Washington, DC

United nations' Office for Disaster Risk Reduction (UNDRR): United Nations International Strategy for Disaster Reduction (UNISDR) strategic framework 2016-2021

United Nations. (2023). Global Sustainable Development Report, *Department of Economic and Social Affairs*

Valdiya, K.S. (1976). Himalayan transverse faults and folds and their parallelism with subsurface structures of the northern Indian Plains. *Tectonophys* 32: 353–386

Valdiya (1985). Accelerated erosion and landslide-prone zones in the Himalayan region. *In*: J.S. Singh (Ed) *Environmental Research in Himalaya*, Central Himalayan Environmental Association, Nainital, pp. 39–53

Valdiya, K.S. (1987). Environmental geology. Indian Context. New Delhi: Tata-McGraw Hill. 583pp

Valdiya, K.S. (2001). Dynamic Himalaya. Jawaharlal Nehru Centre for Advanced Scientific Research. Universities Press (India) Limited

Valdiya, K.S. (2004a). Coping with Natural hazards: Indian Context. (Ed.). The National Academy of Sciences, Allahabad

Valdiya, K.S. (2004b). Geology, Environment and Society. Universities Press (India) Private Limited, 3-6-752, Himayatnagar, Hyderabad 500 029 (A.P). India

Valdiya, K.S., & Bartarya, S.K. (1989). Problem of mass-movement in part of Kumaun Himalaya. *Curr Sci* 58:486–491

VanDer, Knijff J., Jones, R.R.J., & Montanarella, L. (1999). Soil erosion risk assessment in Italy. Office for Official Publications of the European Communities, Luxembourg, p 32, EUR 19022(EN)

Verstappen, H. (1983). Applied Geomorphology: Geomorphological Surveys for Environmental Development. Elsevier, New York.

Wang, C.X., Zhou, J.W., & Zhang, C.B. (2023). Failure mechanism analysis and mass movement assessment of a post-earthquake high slope. *Arab J Geosci* 16: 683. https://doi.org/10.1007/s12517-023-11737-y

Wang, Z., Lai, C., Chen, X., Yang, B., Zhao, S., &Bai, X. (2015). Flood hazard risk assessment model based on random forest. *Journal of Hydrology*,527, 1130–1141. https://doi.org/10.1016/j. jhydrol.2015.06.008

Wentworth, C. K. (1950). A Simplified method of determining the average slope of land surfaces. *Am. J. Science*., Series 5, 20

Wischmeier, W.H., & Smith, D.D. (1978). Predicting rainfall erosion losses. Agriculture Handbook No. 537. US Department of Agriculture, Washington, DC, pp 285–291

Wheeler, T.R., Craufurd, P.Q., Ellis, R.H., Porter, J.R., & Prasad, P.V.V. (2000). Temperature variability and the yield of annual crops. *Agriculture Ecosystems & Environment* 82, 159-167

Yhoshii, K. and Krishnaiah, Y.V.: Landslide Hazard Zonation Map of Kohima, Nagaland using GIS-Based Approach. Department of Geography, Nagaland University, Lumami India.

Youe-Qing, X., Xiao-Mei, S., Xiang-Bin, K., Jian, P., & Yun-Long, C. (2008). Adapting the RUSLE and GIS to model soil erosion risk in a mountain's karst watershed, Guizhou Province, China. *Environ Monit Assess* 141(1–3):275–286

List of Publications and Papers Presented

Publications:

1. **Belho, Khrieketouno**, Rawat, M.S. & Rawat, P.K. (2024). Geospatial Analysis of Seismotectonics for Microearthquake Hazard Zonation in Kohima District, Northeastern Himalayan Region of India. ***Indian Geotech J***. https://doi.org/10.1007/s40098-023-00852-y
2. **Belho, Khrieketouno**, Rawat, M.S. & Rawat, P.K. (2024). Anthropogenic climate change accelerating monsoon hydrological hazards in Northeastern Himalayan region of India: geospatial approach. ***Arab J Geosci*** **17, 67**. https://doi.org/10.1007/s12517-024-11871

3. **Belho, Khrieketouno**, Rawat, M.S. & Rawat, P.K (2023). GIS modeling to investigate environmental change and degradation in Kohima district, North East Hill (NEH) region of India. ***Environ Monit Assess*** **195, 1553**. https://doi.org/10.1007/s10661-023-12055-2
4. **Belho, Khrieketouno** and Rawat, M. S. (2023). Geographical Perspective of Geomorphological Hazards in Kohima District of Nagaland. ***International Journal of Scientific Research in Science, Engineering and Technology, Vol 10, issue 2, p.86-92*** *(Print ISSN: 2395-1990 | Online ISSN23944099 (www.ijsrset.com) doi: https://doi.org/10.32628/IJSRSET2310211).*
5. **Belho, Khrieketouno** and Rawat, M. S. (2023). Response of Hydro-Meteorological Hazards to Environmental Degradation in Kohima District of Nagaland, North East India. ***International Journal of Scientific Research in Science, Engineering and Technology Vol 10, issue 1, p.339-349*** *(Print ISSN: 2395-1990 Online ISSN: 2394-4099 (www.ijsrset.com) doi: https://doi.org/10.32628/IJSRSET2310146).*

Papers Presented:

1. Presented a paper entitled ***Anthropogenic climate change accelerating monsoon hydrological hazards in Kohima district, Northeastern Himalayan region of India: Geospatial approach*** in the ***ICSSR-New Delhi sponsored Two Days National Seminar on Anthropology in the 21st century: Emerging Areas of Research in***

Northeast India and its Role in National Development organized by the ***Department of Anthropology, Nagaland University, Lumami 798627 held on 19th and 20th March, 2024.***

2. Presented a paper entitled ***Impact of Geomorphological Hazards on Bioresources Degradation in Kohima District of Nagaland*** in the ***International Conference on Bioresources and Bioeconomy*** organized by the ***Department of Botany, Nagaland University, Lumami 798627, Nagaland, India held on September 19-21, 2022.***

3. Presented a paper entitled "***Response of Hydro-Meteorological Hazards to Environmental Degradation in the Kohima District of Nagaland"*** in the ***International Symposium on Integrated Land Use Management in the Eastern Himalayas- Focus on Nagaland*** organized by the ***Department of Botany, Kohima Science College, Jotsoma, Nagaland, India in collaboration with the University of Minnesota, USA*** *from* ***12th -14th March, 2019.***