



**ASSESSMENT OF GEOMORPHOLOGICAL HAZARDS IN
MOKOKCHUNG DISTRICT, NAGALAND**

**THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY**

By

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**ASSESSMENT OF GEOMORPHOLOGICAL HAZARDS IN
MOKOKCHUNG DISTRICT, NAGALAND**

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PROF. M.S. RAWAT**

**Submitted in partial fulfillment of the requirements for the Degree
of Doctor of Philosophy in Geography of Nagaland University**

*With love and remembrance, this thesis is dedicated to my father,
Mr. Ojensüingba Pongen.
Oba, you live on in my heart and in every achievement I reach.*



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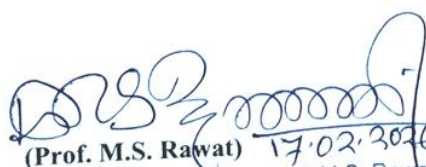
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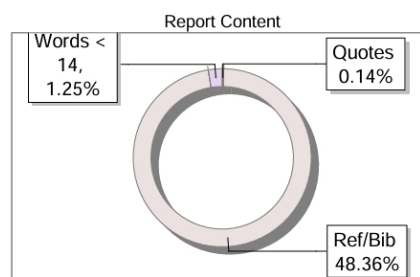
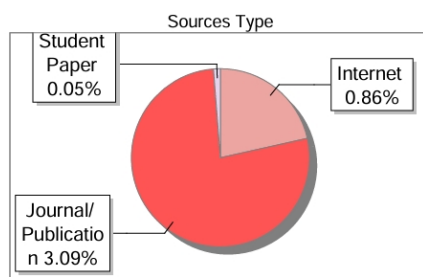
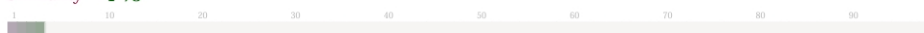
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INTRODUCTION

Geography is the discipline that studies the earth, its physical aspects, and the complex relationships between humans and the environment in which they live. It encompasses both the natural aspects of the earth's surface and the spatial distribution of human activities. Ackerman (1958) emphasized that the key concept of geography lies in the differentiation of the content of space on the earth's surface and in the analysis of the spatial relations within the same universe. Basing on this view, Hartshorne (1959) described geography as the provision of "accurate, orderly, and rational description interpretation of the variable character of the earth's surface". Later, Haggett (1969) emphasized the idea of space as central to geography, describing it as the study of the Earth's surface as the living space of human populations. Taken together, these perspectives highlight two fundamental ideas in geography: spatial association and areal differentiation. Spatial association refers to understanding how natural and human features are linked across space, while areal differentiation focuses on what makes one place distinct from another. Geography, therefore, is not only concerned with mapping patterns but also with explaining how and why those patterns develop and change over time.

Geography is broadly divided into two main branches: Physical geography and Human geography. Physical geography explores natural systems and landforms, whereas human geography examines population patterns, culture, economic systems, and political organization. In recent years, scale has become increasingly important in geographical research, with studies ranging from highly localized investigations to global analyses. At the same time, technological advancements such as Geographic Information Systems (GIS), Remote Sensing, and spatial modeling have greatly improved the accuracy, scope, and practical application of geographical studies. Within physical geography, geomorphology holds a distinctive position. Because landforms are shaped by both internal and external forces, geomorphology draws from environmental sciences as well as geology. It overlaps with climatology, hydrology, soil science, and ecology, while also connecting closely with tectonics, structural

geology, sedimentology, and stratigraphy. These relationships influence not only the subject matter but also the spatial and temporal scales at which geomorphological studies are conducted.

Earlier geomorphological studies relied heavily on descriptive observation and classification of landforms. However, during the 20th century, major advances in plate tectonic theory, radiometric dating, aerial photography, geochronology, and quantitative modeling transformed the discipline. The focus gradually shifted from simply describing landscapes to explaining the processes behind them and, increasingly, to anticipating future changes. Today, geomorphologists combine field surveys, digital elevation models, satellite imagery, GIS analysis, and numerical modeling to understand interactions among tectonics, erosion, deposition, and climate.

One of the practical strengths of geomorphology lies in its ability to identify stable terrain and areas where the likelihood of natural or human induced hazards is relatively low (Rosenfeld, 2004). Because many natural hazards are directly linked to surface processes, geomorphology plays a central role in hazard assessment. Landslides, floods, coastal erosion, earthquakes, and volcanic activity are all connected, in one way or another, to geomorphic dynamics. Rather than viewing these events in isolation, geomorphology places them within the broader context of an evolving landscape.

A hazard can be understood as a natural or environmental process that has the potential to cause harm to people, property, or socio-economic systems. Tobin et al. (1997) described natural hazard as the probability that a damaging natural phenomenon will occur within a specific area over a given time period. Importantly, natural processes become especially dangerous when they intersect with human settlements and infrastructure. For instance, building on floodplains increases exposure to floods, while construction on unstable slopes heightens landslide risk. In this way, risk emerges from the interaction between environmental processes and human decisions. Activities such as deforestation, rapid urban growth, and industrial expansion can further intensify both the frequency and severity of hazardous events. When such events lead to major disruption and widespread damage, they are referred

to as disasters. Distinguishing clearly between natural and human causes is often difficult because the two are deeply interconnected.

Geomorphological hazards form a specific category within this broader framework. They involve processes that alter the shape, structure, or stability of the Earth's surface. These may include landslides, soil erosion, desertification, flooding, drainage modification, and even landscape changes linked to extreme weather events. Panizza (1986) and Kalvoda (1996) define geomorphological hazards as the potential occurrence of significant or highly dynamic geomorphic processes at a particular location and time. In practical terms, this may involve estimating the likelihood of a landslide in a defined area over several decades. Slaymaker (2010) suggests that a geomorphic hazard arises when landscape instability interacts with human land use, producing social or economic consequences. Gates (1994) similarly notes that a hazard becomes geomorphic when it leads to observable changes in the landscape itself. The severity of such hazards is often linked to geological structures shaped by internal (endogenetic) forces such as tectonic movements and active faults. At the same time, external (exogenetic) processes particularly extreme rainfall and climatic variation modify and reshape existing landforms. Together, these forces influence valley morphology, drainage networks, river terraces, alluvial fans, gully erosion, and flash flood development (Rawat, 2011). Among these hazards, landslides and mass movements receive particular attention because of their frequency and the scale of damage they can cause to settlements and infrastructure.

1.1. Statement of the Problem

Hazards are a fundamental concern in the subject matter of geography. Research into geomorphological hazards presents an opportunity to develop conceptual models and understand the general principles of the origin of natural disasters (Goudie and Kalvoda 1997 & Demek et al. 2006). India is one of the leading hazard prone countries in the world owing to its proximity to geodynamically active locales and unique climatic pattern. Both these factors in different combinations has led to the occurrence of disasters resulting from natural hazards such as droughts, floods, earthquakes, and cyclones, and landslides in various parts of the country at frequent intervals, which

affect millions of people every year. Its long coastline, major river systems, and mountainous terrain contribute to the risk, while rapid urbanization and deforestation further increase the impact of these hazards. The Himalayan mountains and the Northeast region in particular are susceptible to a broad range of potentially hazardous geomorphological and hydrometeorological processes, including rock falls, landslides, debris flow, soil erosion, flash floods, avalanches, and cloudbursts in higher ridges. The Northeast region exemplifies the increasing risk posed by natural hazards in a mountain environment. The severity of mass movement has posed threats to lives and resources in the region. Nagaland, located in the northeastern region of India, is highly prone to geomorphological hazards owing to the distinctive geo-environmental setting of the region. The highly intense monsoon regime, weak geological formation, frequent seismic activity, accelerated erosion, rapid channel aggradations, extensive deforestation, intense land use pressure, and massive hill road construction are some of the key factors responsible for the intensity of geomorphic hazards. The region experiences a range of hazards, including landslides, soil erosion, floods, earthquakes, and deforestation-induced hazards, which are the outcome of interaction between physical processes and human activity. Mokokchung, a district in the Nagaland state of Northeast India is the focus of the present research.

1.2. Study Area

Mokokchung district is located in the north eastern part of India, within the state of Nagaland and is encircled by the state of Assam to its north, Tuensang to its east, Zunheboto to its south and Wokha and Assam to its west. It covers an area of approximately 1,615 sq km and lies between 94° 29' E to 94° 76' Longitude and 26° 20' N to 26° 77' N Latitude. Elevation in the district varies from about 180 meters to 2000 meters above mean sea level. Mokokchung is drained by Milak, Dikhu, Tsurang, Tsumok and Menung and their tributaries, flowing generally westward toward the Brahmaputra basin. The district is characterized by its undulating terrain, lush green valleys and dense forests and is inhabited predominantly by the Ao Naga tribe.

The study area is geologically and geomorphologically active, making it prone to various hazards. Geomorphological hazards in the region occur due to natural

processes as well as human activities. The rocks in the area have low compressive strength and when exposed to a humid climate and heavy rainfall, they undergo deep weathering and erosion. These conditions, combined with young geological formations, steep slopes, high relief, intense rainfall, and improper land-use practices, are the main causes of hazard occurrence. Rapid population growth and the increasing concentration of people in hazard prone areas, along with inadequate infrastructure, have further increased the frequency and severity of hazards. In addition to risks to human life and livestock, businesses and infrastructure, particularly along major highways in Mokokchung district, are highly vulnerable. This often results in frequent road blockages and transport disruptions. Although geomorphological hazards cannot be completely prevented, understanding the processes involved and applying suitable technical methods for hazard assessment and forecasting can significantly reduce vulnerability. Therefore, a comprehensive study of geomorphological hazards that integrates both physical and human factors is essential for developing effective mitigation strategies. Such an approach can help reduce risks, strengthen disaster resilience, and support sustainable development in the study area and the wider northeastern hill region.

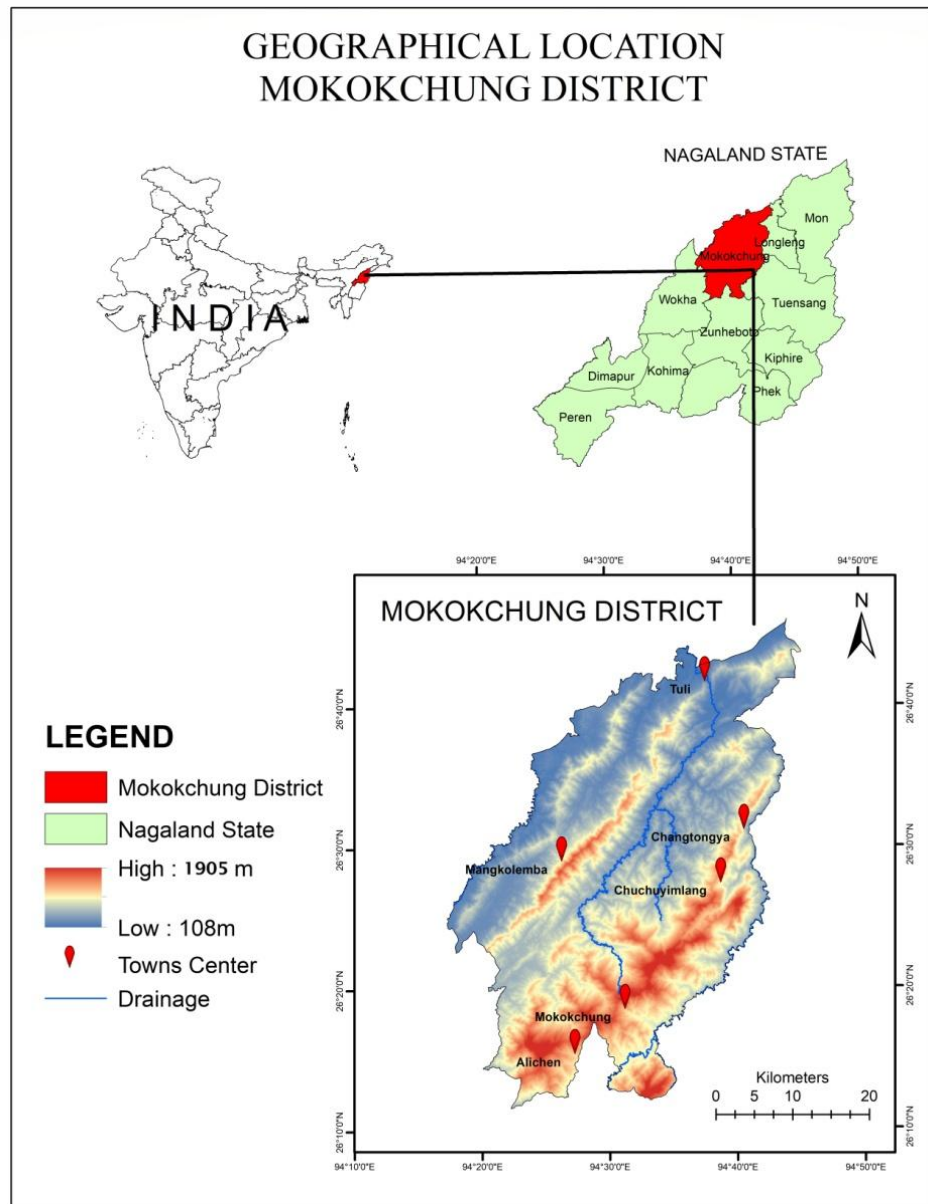


Figure 1.1: Location Map of the Study Area viz. Mokokchung District of Nagaland, Northeast India.

1.3. The Objectives of the Study

Not much is known about the geomorphological hazards in Nagaland as a whole. Considering the less availability of literature and the ever increasing adverse effects of different hazards in the environment, the present study on the assessment of geomorphological hazards in Mokokchung district of Nagaland has been undertaken with the following objectives:

- i. To identify and assess the different geomorphological hazards occurring in the study area
- ii. To examine the causes behind geomorphological hazards
- iii. To prepare geomorphological hazard maps using toposheets and satellite imagery
- iv. To analyze community and government based disaster management activities and programs
- v. To propose strategies for the management and mitigation of geomorphological hazards

1.4. Database and Methodology

To fulfill the objectives of this study, a comprehensive and multi-dimensional methodology was undertaken for assessment of geomorphological hazards in Mokokchung district. The methodology incorporates field observations, GIS techniques, and analytical modeling. It involves a systematic collection of diverse datasets such as topographical, geological, meteorological, and seismological, and their integration in a GIS framework to prepare a comprehensive geomorphological and geographical hazards database.

1.4.1. Materials

- i. Literature and scientific reports (published papers, research articles, books and government publications).
- ii. Survey of India toposheets: 83 J/2, J/3, J/6, J/7, J/9, J/10, J/11, J/14, and J/15 (scale 1:50,000).
- iii. Google Earth and other high-resolution satellite imageries.
- iv. Geological data from the Geological Survey of India (GSI) and directorate of Geology and Mining, Nagaland.
- v. Soil datasets from the National Bureau of Soil Survey and Land Use Planning (ICAR).
- vi. Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM).
- vii. Meteorological data (rainfall intensity, climate variability, temperature)

- viii. Seismological records.
- ix. ArcGIS software, Remote Sensing software, and statistical analysis tools.

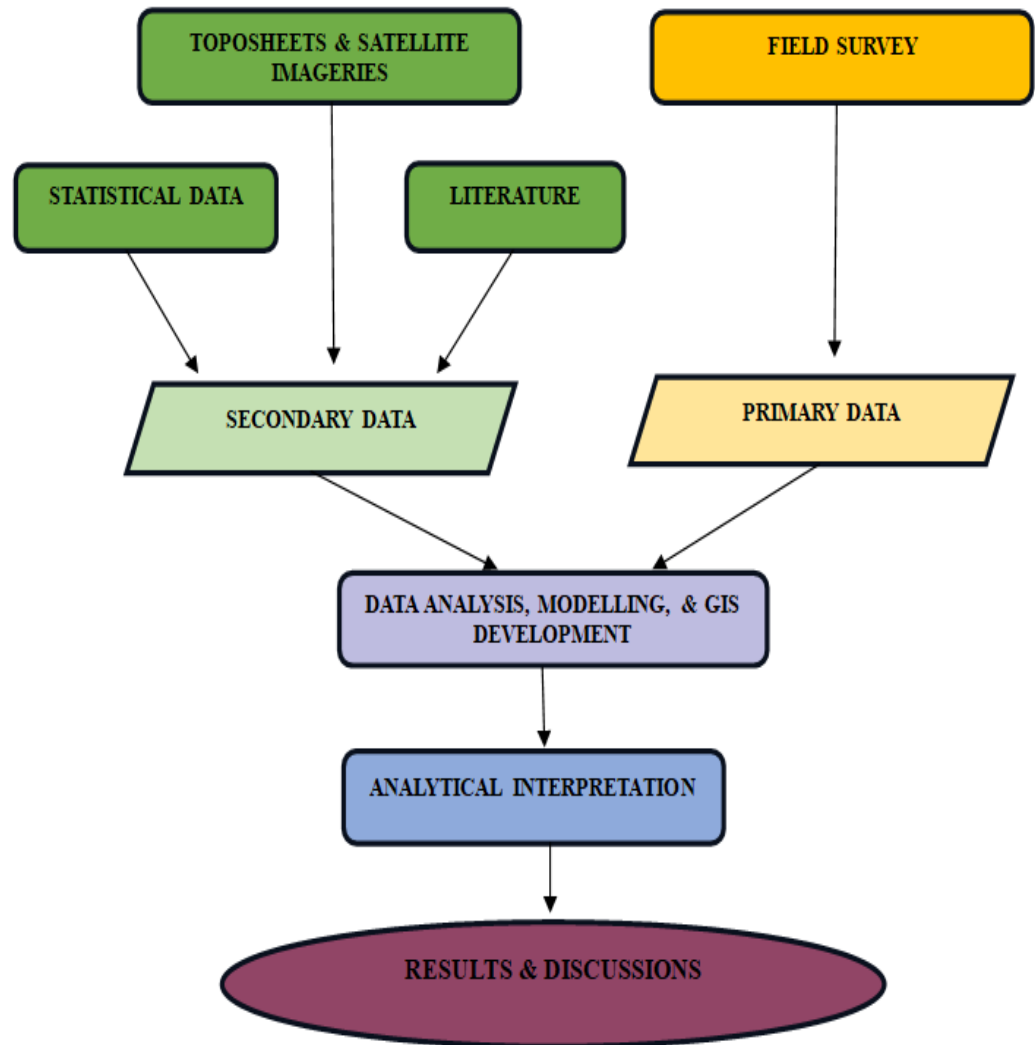


Figure 1.2: Methodology flow chart for the study.

1.4.2. Geospatial Database Development

To compile detailed information on the geo-environmental attributes of Mokokchung district, including slope, relief, lithology, drainage, geomorphology, seismic activity, soil properties, and topographic, meteorological, and biological factors were evaluated. Major geomorphological hazards such as landslides, soil

erosion, flash floods, and earthquakes directly correlate with these parameters. GIS base maps were produced using a combination of Survey of India toposheets, DEM data, remote sensing images, and ground survey inputs. All datasets were georeferenced and integrated into the GIS framework for processing spatial database.

1.4.3. Models and Approaches

The Analytical Hierarchy Process (AHP) developed by Saaty (1980) was employed for evaluating the relative weight and priority of the causative factors and sub factors of landslides and flash floods in the study area. AHP is one of the multi-criteria decision making (MCDM) methods of measurement through pair-wise comparisons and relies on the judgments of the experts to derive priority scales (Saaty, 2008).

Soil erosion assessment was undertaken using the Revised Universal Soil Loss Equation (RUSLE), originally developed by Wischmeier and Smith (1978). The spatial factors, including rainfall erosivity, soil erodibility, slope length and steepness derived from DEM, land cover, and conservation practices were integrated into the RUSLE model in GIS framework in order to estimate long term average annual soil loss and to delineate erosion prone zones.

To perform a seismotectonic hazard analysis, a dual approach was combined which included the Scalogram Modeling Technique (Cruz, 1992) and the Analytical Hierarchy Process (Saaty, 1980). This integration system was used to prepare tectonic lineament maps, regional seismic records, and structural features for identifying vulnerable seismic zones.

A strategic management framework, SWOT analysis is a planning tool that is used to identify an organization's Strengths, Weaknesses, Opportunities and Threats in a participative manner. The SWOT analysis was used to identify and characterize the district's distinctive strengths, weaknesses, opportunities, and threats. This information helped in preparing specific mitigation measures, recommendation of policies, and preferred adaptation measures for geomorphological hazards in Mokokchung district.

1.5. Literature Review

Geomorphology is essentially the study of the Earth's surface, focusing on the forms it takes and the natural processes that create and continually reshape those forms (Montgomery & Bierman, 2013). Earlier, Derruau (1965) simply described it as the study of the landforms that make up the Earth's relief. Over time, the discipline has come to occupy a space between physical geography, with its emphasis on environmental systems, and geology, which focuses more on the structure and composition of the solid Earth (Harvey, 2012). Panizza (1996) further clarified the scope of geomorphology by defining it as the study of the contact zone between the lithosphere and either the atmosphere or hydrosphere, where active geomorphic processes take place. Within the context of hazards, Sperber (2001) defined hazards as agents capable of causing damage to human life, property, or the environment. Geomorphic hazards, in particular, stem from the instability of the Earth's surface (Gares, 1994). They arise because landscapes are not static but instead they are continuously being reshaped by natural forces. When these processes intersect with human settlements and activities, the consequences can be significant. Academics have classified these into three broad categories: Endogenous hazards, such as volcanism and tectonic activity, Exogenous hazards, including floods, erosion, avalanches, and mass movements, and climate and land-use induced hazards, such as permafrost degradation, desertification, and soil erosion (Slaymaker, 1996 & Ayala, 2002).

Panizza (1996) defined geomorphological hazards as the probability that specific landform instability will occur within a given area and time period, potentially affecting human activities. In contrast to sudden disasters like earthquakes, many geomorphological hazards tend to develop slowly, sometimes over decades or even longer (Gares et al., 1994). Yet their gradual nature does not make them less dangerous. Their effects can become serious when people build homes, roads, and other infrastructure in areas that are naturally unstable (Ayala, 2002). For this reason, one of the most important contributions of geomorphological research has been the identification of stable ground and the mapping of hazard prone zones (Rosenfeld, 2004). Geomorphologists have long been involved in hazard studies, drawing on

detailed fieldwork, remote sensing techniques, and predictive models to locate, monitor, and map areas at risk. As Verstappen (1989) pointed out, geomorphology is inherently multidisciplinary. It brings together an understanding of how landscapes evolved in the past, how they are changing today, and how human activities are altering natural processes. This combined perspective makes the discipline especially valuable for hazard assessment and risk management.

The growing use of GIS, remote sensing, and quantitative approaches has made prediction and mitigation efforts more accurate and reliable (Rosenfeld, 1994). The use of historical geomorphic data to predict future hazard occurrences such as floods and landslides has become an integral part of applied geomorphology (Baker, 1994). Understanding geomorphic phenomena in terms of their frequency and magnitude also helps in predicting future trends and suggesting suitable mitigation measures (Griffiths, 2001; Goudie, 2010). These efforts have been strengthened by technological advancements that allow detailed spatial analysis (Bilwa et al., 2015). Modern geomorphology has undergone major methodological changes over the years. A key focus has been the relationship between landforms and the processes currently acting upon them (Summerfield, 1991). The discipline has shifted from traditional geographical geomorphology to geophysical and quantitative geomorphology, which uses numerical methods and advanced technologies (Summerfield, 2005). In tropical regions, the development of process geomorphology marked an important transition from qualitative description to quantitative analysis (Douglas, 1977; Faniran & Jeje, 1983).

Over time, geomorphology expanded beyond the study of natural landforms to include human interactions and risk reduction, a field commonly referred to as applied geomorphology (Thornbury, 1954; Ayala, 2002). In this context, geographers trained in geomorphology are particularly well positioned to contribute to hazard management, as they bring an integrated understanding of physical landscape processes alongside human systems and settlement patterns (Ayala, 2002).

For many years, geomorphological research in India mostly followed a conventional approach, focusing mainly on erosional surfaces, landscape evolution,

and theoretical models of landform development. However in recent decades there has been a shift towards more applied and hazard focused research. The adoption of remote sensing and Geographic Information Systems (GIS) has significantly improved the accuracy of mapping, hazard zonation, and predictive modeling (Kale & Gupta, 2001). At the same time, advances in quantitative methods and digital terrain analysis have strengthened the analytical depth and scientific rigor of geomorphological investigations (Hart, 1986). There is now a broader recognition that human activities strongly influence the frequency, magnitude, and severity of geomorphological hazards. Changes in land use and unplanned urban expansion, deforestation, and intensive resource exploitation often intensify processes such as landslides, floods, and soil erosion. Rawat (2011) emphasized that geological disturbances can become far more destructive when altered by human intervention, highlighting the importance of hazard mapping and zonation in risk reduction. Similarly, Goudie's (1997) concept of anthropo-geomorphology highlights the active role of human agency in reshaping landscapes and altering geomorphic processes.

In recent years, remote sensing and GIS have become indispensable tools for identifying risk prone areas by developing predictive models, and improving disaster management strategies (Bilwa et al., 2015). The integration of traditional geomorphic knowledge with modern technological tools has created a comprehensive framework for evaluating, forecasting, and mitigating geomorphological hazards. As human settlements continue to expand into dynamic and fragile environments, the scientific and applied role of geomorphology has become increasingly important. Continuing advances in technology are expected to further strengthen research aimed at reducing geomorphological hazard risks and enhancing resilience in vulnerable regions. Recent studies by Belho (2024), Belho et al., (2024a and 2025a&b) among others, provide valuable contributions to the study of geomorphological hazard assessment.

1.6. Scope of the Study

The ever increasing adverse implications that come along with different hazards in the environment which a number of populations are faced with make it necessary for a study and analysis on the different geomorphological hazards in Mokokchung

district and the various effects brought about by the same. A key principle in understanding hazards is recognizing that they occur repeatedly; thus, examining their past occurrences offers essential insights for developing effective hazard reduction strategies (Keller and DeVecchio, 2016). An assessment of different hazards in an area of interest is a prerequisite for any development activities. This makes it crucial to identify the causes of each hazard and the associated casualties, which is the aim of the present study. Considering the region's varied topography and its susceptibility to natural disasters, the present study has attempted to assess the geomorphological hazards comprehensively occurring in the region through a geospatial approach and accordingly suggest mitigation and management measures by integrating both natural and anthropogenic factors. The study focuses on mapping and monitoring geomorphological hazards by using modern geospatial technologies, particularly Remote Sensing and GIS. By integrating multidisciplinary and comparative methods, it aims to develop a comprehensive framework to improve risk assessment, strengthening disaster preparedness, and promoting sustainable land management strategies. This study will play an increasing role in strengthening applied research by using advanced techniques while emphasizing the importance of sustainable development. It will provide valuable insights to mountain environmental studies, geography, geomorphology, hazard and disaster mitigation and management. The findings will be useful to a wide range of communities, including geographers, geomorphologists, geologists, hydrologists, meteorologists and environmental scientists.

The study will hold great significance in the fields of environmental and applied geomorphology, hazard management, and sustainable development by generating updated geospatial data in order to support accurate decision making and evidence based policy formulation. The study also aims to provide a basis for further research in hazard management while proposing comprehensive strategies for mitigation and management of geomorphological hazards. It emphasizes the importance of integrating hazard assessments into infrastructure planning, land-use policy, and resource management thereby equipping policymakers and planners with reliable scientific tools for effective disaster risk reduction. This study will enhance the

resilience of communities by raising awareness of geomorphological hazard risks and emphasizing the importance of proactive adaptation and mitigation strategies. Additionally, it supports global sustainability goals by promoting resilient ecosystems, reducing disaster impacts, and ensuring long term environmental security, especially in vulnerable areas like Mokokchung district and Nagaland.

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GEOGRAPHICAL OVERVIEW OF MOKOKCHUNG DISTRICT

Geography is broadly understood as a discipline that examines the spatial relationships between people, places, and natural systems in order to explain how environments function and how interaction of human and environment takes place (de Blij, Murphy & Fouberg, 2010). Geography is broadly divided into two main branches: Physical Geography and Human Geography. Physical Geography focuses on natural processes and landforms, while Human Geography examines population, culture, economic activities, and political systems. Understanding both the branches is essential when studying geomorphological hazards, since such hazards emerge from the interaction between natural earth processes and human actions.

Physical geography is concerned with the natural features of the Earth and the processes that shape them, including the atmosphere, landforms, water bodies, soils, vegetation, and the relationships among these components (Strahler & Strahler, 2009). It looks at how these elements vary across space and change over time within different regions. By studying how physical systems function and evolve, physical geography helps explain the environmental conditions that influence human activities. The field includes several sub-disciplines such as geomorphology, climatology, pedology, oceanography, and biogeography, which deal with landforms, climate, soils, oceans, and the distribution of plants and animals. Through these areas of study, physical geography contributes to hazard assessment and risk reduction by examining events like floods, earthquakes, and volcanic eruptions. It also supports sustainable resource management, climate change research through the analysis of shifting weather patterns, and broader environmental conservation efforts aimed at maintaining a balance between natural processes and human needs.

Basing on these concepts, the physical geography of the study area has been studied in order to better understand its natural setting and environmental dynamics. Such an understanding provides a necessary basis for assessing geomorphological hazards and associated risks faced by the communities. Physiographically, Nagaland can be broadly divided into three mountain ranges aligned in a northeast-southwest direction: the Eastern mountain ranges (high hill ranges) in the east, the middle hilly ranges (medium high hill ranges) in the central region, and the Western Low Ranges (Figure 2.1). Covering an area of 16,579 km², the state lies within the North-East Hill (NEH) region and has an elevation range from 194 m to 3048 m above mean sea level. Its climate varies from sub-temperate to sub-tropical. Nagaland is marked by rugged terrain, lofty peaks, high mountain ranges and small plains which significantly influence the distribution of population and the cultural landscape of Nagaland (Furkumzuk, 2011). Its eastern part is formed by the Patkai Range, while the Barail Range enters from the southwest and merges with the Patkai beyond Kohima. The highest peak, Saramati (3826 m), lies near the Myanmar border, followed by Japfu (3014 m), Kahu (2841 m), Paona (2791 m), and Kapamodzu (2429 m). Although dominated by hills, the state has small but important plains such as the The Dimapur Plain, covering about 150 km² and forms the largest lowland area, merging into Golaghat district of Assam. Other notable plains include the Naganimora Plain (50 km²) and the Tizit Plain (75 km²) in Mon District. The foothills and outer ranges, with elevations between 110 and 600 meters, act as a transitional zone between the Assam plains and the rugged interior hills. The intricate geological formations and the tectonic forces that have uplifted these mountain ranges, along with processes such as weathering, erosion, mass movements, seismic activity, and other factors, significantly impact and alter the natural ecology of the area. Nagaland is located in Zone V on the seismic map, which represents the highest risk for earthquakes. In this zone, the magnitude of earthquakes can surpass 8, making the state highly vulnerable to seismic activity. The state has numerous geological faults that experience frequent tectonic movements, and are highly susceptible to slope failure, landslides and soil erosion.

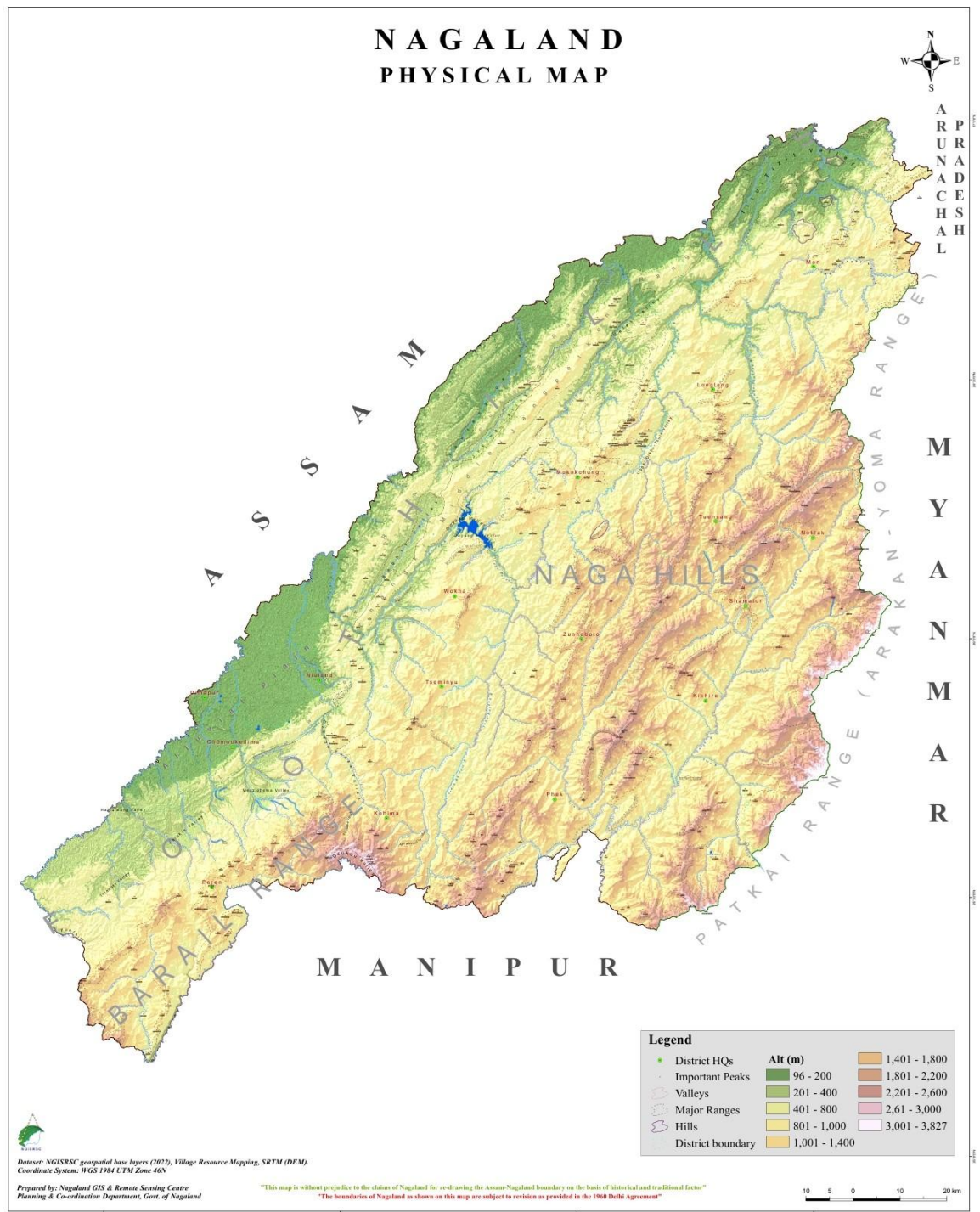


Figure 2.1: Physical Map of Nagaland (Source: Nagaland GIS and Remote Sensing Centre, Kohima, NGISRSC, 2022).

2.1.1. Physiography

Physiography is a major aspect of physical geography which studies the structure and evolution of landforms and their profound impacts on environment and ecosystems. Mokokchung district is comparatively lower in elevation as compared to other districts of Nagaland. It is a segment of the Naga Hills, which forms a fragmented extension of the Eastern Himalayas. The elevation varies from 150 to 1995 meters above mean sea level and includes several mountain ranges, hills, steep crust ridges, narrow valleys, and a few patches of plains, along with several rivers and streams. It predominantly disseminates in a northeast and southwest direction. The elevations are greater in the east compared to the west, where they converge with the plains of Assam. Between hills, there are glens and gorges through which streams traverse.

The physiography of Mokokchung district (Figure 2.2) is characterized by six distinct and nearly parallel hill ranges with varying climates, soils, terrains, and vegetation characteristics. These ranges namely: Ongpangkong, Langpangkong, Asetkong, Jangpetkong, Japukong, and Tzürangkong generally extend in a North-East or South-West direction. Most of these ranges are characterized by steep slopes although certain sections display gentler gradients. Overall, the eastern ranges are comparatively higher than those in the west, where the terrain gradually descends and merges with the plains of Assam.

Ongpangkong range: The Ongpangkong range is the southernmost and highest range of Mokokchung district, with an average elevation of 1500 meters above mean sea level. It forms an uneven boundary of the district, bordered by Wokha and Zunheboto districts to the south and Tuensang district to the east. Due to its higher elevation, this range experiences relatively colder climatic condition compared to the other ranges. It covers a large geographical area and is characterized by extensive stretches of dense and largely pristine forest. The highest altitude village in the district namely Longkhum is located within this range at an elevation of approximately 1846 meters above mean sea level.

Langpangkong range: The Langpangkong range is the easternmost range of the district and is noted for its bed-like formation. Closely aligned with the course of the Dikhu river, it forms a natural boundary between Mokokchung district and the neighboring districts of Mon and Tuensang. Within the whole of Mokokchung, this range supports extensive and deep forest cover, providing a habitat for a rich diversity of flora and wildlife.

Asetkong range: The Asetkong range is situated between the Menung and Milak rivers and serves as the core range among all the ranges. It stretches in an east-west direction, bordered by the Langpangkong range to the east, Ongpangkong to the south, and the Jangpetkong range to the northwest, resembling an island. The mean elevation of the range is 1100 meters above sea level and is characterized by rocky terrain, fertile soils, abundant rainfall, and a warm, humid climate. Its relatively undisturbed natural vegetation supports a wide diversity of plant and tree species along with rich wildlife.

Jangpetkong range: It runs parallel to Japukong and is located between the Milak river on the east and the Tzürang river on the west. The landscape is covered with a mix of evergreen and deciduous forests and is notable for its variety of natural resources, including coal deposits. It is the outermost regular range extending from northeast to southwest, situated to the inner part (south) of the Tzürangkong. It extends around 70 kilometers in length, with an altitude ranging from 150 to 950 meters above mean sea level. The region experiences a warm-humid, subtropical climate characterized by dense, thick forests.

Tzürangkong range: Characterized by warm and humid weather conditions, the Tzürangkong range adjoins Assam and extends around 15 kilometers from the Tsürang river to the Tzütapela region. It comprises randomly situated hillocks that border the plains of Assam, primarily along the valleys of the Desai and Jhanzi rivers before merging into the Assam plains. Wangtak, Tangyong, and Dzesu are the perennial rivers draining this range.

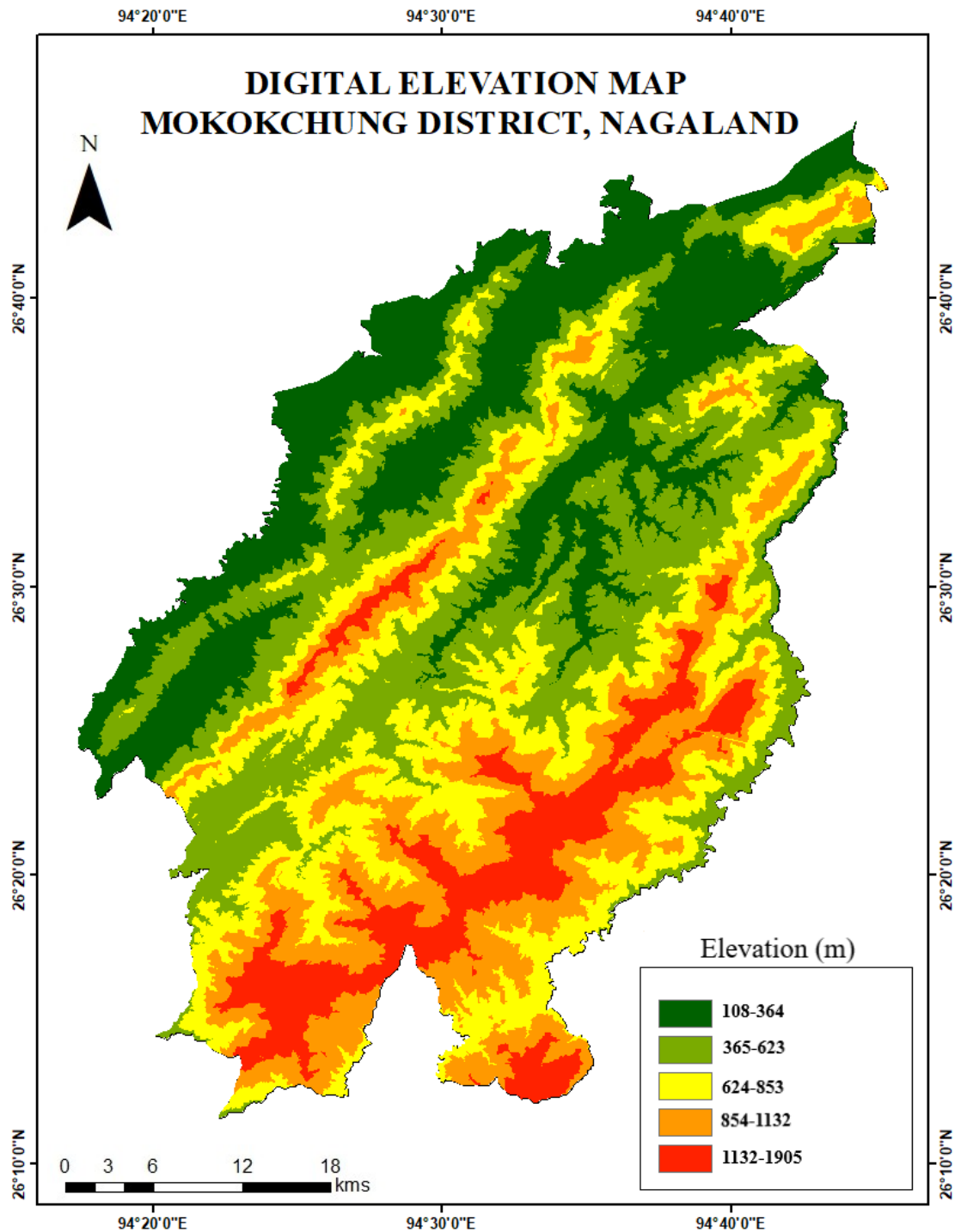


Figure 2.2: Physical Map of Mokokchung District (Digital Elevation Model: DEM).

2.1.2. Geomorphology

The geomorphology of Nagaland is characterized by its rugged mountainous terrain, marked by a combination of dissected hills, steep valleys, and narrow plains as depicted in Figure 2.3. Located in the northeastern part of India, Nagaland forms a part of the Purvanchal mountain system, which represents the eastern extension of the Himalayan and Indo-Burma ranges. The physiography is dominated by two major mountain systems: the Patkai range along the eastern boundary with Myanmar and the Barail range which approaches from the southwest and merges with the Patkai near Kohima. From the west, the terrain rises sharply from the Brahmaputra plains of Assam, resulting in pronounced variations in elevation across the state. Nagaland is characterized by a rugged mountainous terrain with several prominent peaks. Mount Saramati, the highest peak in the state, rises to an elevation of 3826 meters near the Indo-Myanmar border. Other significant peaks include Japfu (3014 m), Kahu (2841 m), and Paona (2791 m). These mountain ranges are marked by steep slopes, deep valleys, and sharp ridges, reflecting ongoing tectonic uplift combined with intense erosional processes. On the contrary, the western part of Nagaland comprises foothills and limited alluvial plains, such as the Dimapur plain, Naganimora plain, and Tizit plain, with elevations ranging between 110 to 600 meters. Despite their narrow extent, these plains serve as important centres of human settlement and agricultural activity within the predominantly hilly terrain. The drainage system of Nagaland is closely influenced by its relief, with rivers flowing through deep valleys before depositing sediments in the form of alluvial fans and terraces in the foothills and plains. The combined influence of tectonic activity, erosional processes, and climatic factors has resulted in a highly dissected and unstable geomorphology. Consequently, the region is particularly vulnerable to geomorphological hazards such as landslides and soil erosion. Nagaland's geomorphology exhibits a complex interplay of geological formations, tectonic activity, and fluvial dynamics, resulting in a varied landscape characterized by lofty mountain ranges, fragmented hills, and narrow fertile plains that influence the state's ecology, settlement patterns, and socio-economic structure.

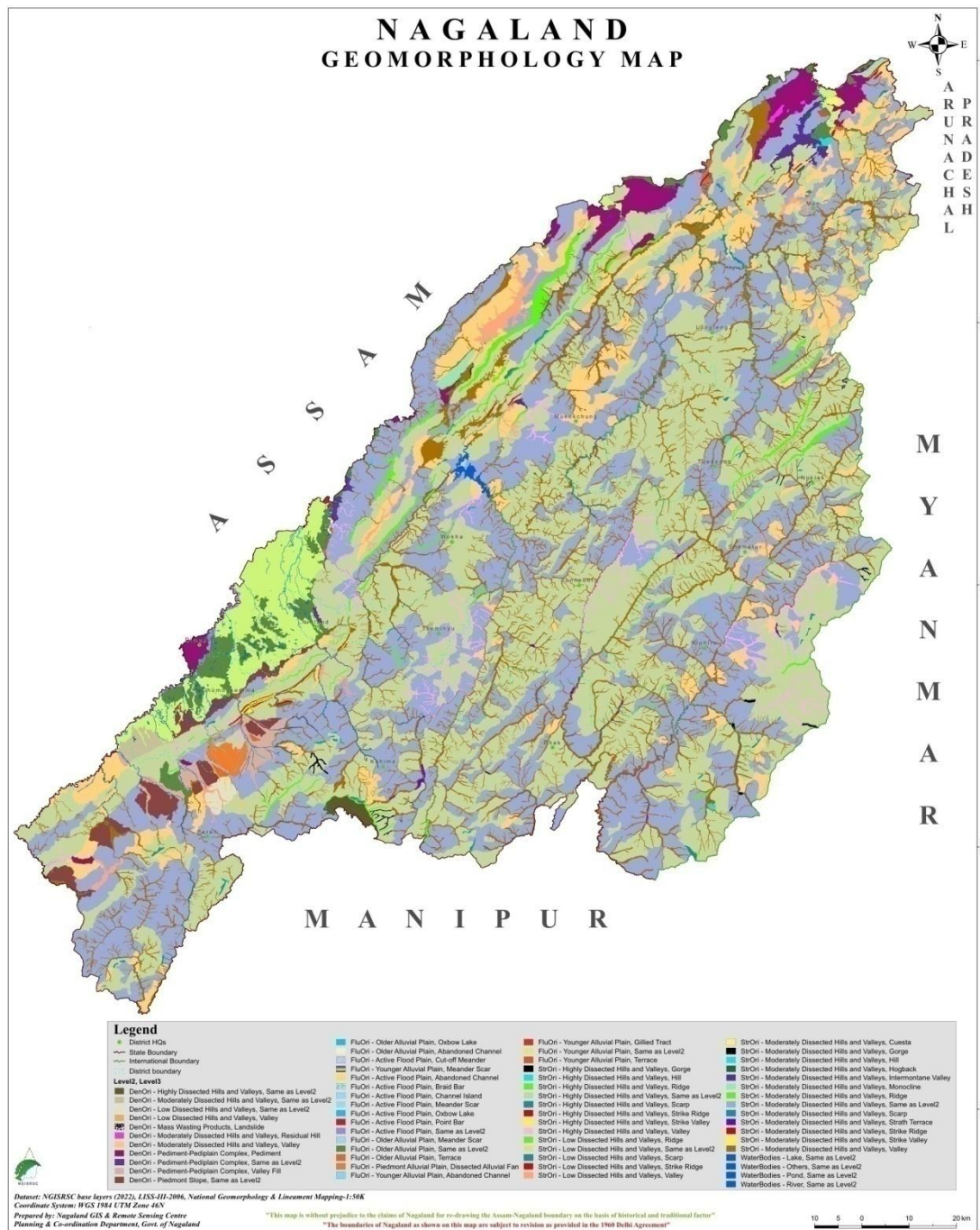


Figure 2.3: Geomorphological Map of Nagaland (Source: NGISRSC, 2022).

The varied geomorphology of Mokokchung is a consequence of the complex interaction between tectonic movements, erosional processes and sediment deposition. The landscape of Mokokchung ranges from steep dissected hills to expansive alluvial plains, which in turn influence diverse land-use pattern and settlements. The

underlying geology, especially formations like the Barail and Disang groups, shapes the topography of the region and has a huge impact on the viability of agriculture, the distribution of settlements and the growth of infrastructure throughout the district. Mokokchung district encompasses several distinct geomorphic units, classified according to slope, rock type, erosional intensity and elevation. These categories as illustrated in Figure 2.4 have been described in detail below:

2.1.2.1. Highly Dissected Structural Hills and Valleys: These areas present a fragmented topography of steep, rugged slopes and sharply incised V-shaped valleys. These prominent features prevail in the northern and southern regions, where the terrain is shaped by persistent geological forces. The slopes are noticeably steep, resulting in rapid surface runoff promoting active erosion and formation of deep gullies. The rocks underlying these hills, primarily the durable and erosion resistant Barail group serves as the base for the regions significant relief. The rugged terrain and recurrent landslides result in sparse settlements, as most population look for safer and more accessible locations.

2.1.2.2. Moderately Dissected Structural Hills and Valleys: These areas form the largest geomorphic unit in the district, extending through a wide central belt from north to south. This region features gently rolling hills and valleys, with slope angles typically ranging between 14° to 33°, resulting in a more accessible and less rugged terrain compared to the highly dissected zone. These areas exhibit a balance between stability and erosions, rendering them suitable for agriculture and settlement compared to the highly dissected zones. The rock composition in the regions is a mix of Barail and Disang group formations. This landscape forms the core inhabitable zone of Mokokchung district due to its moderate relief and accessibility.

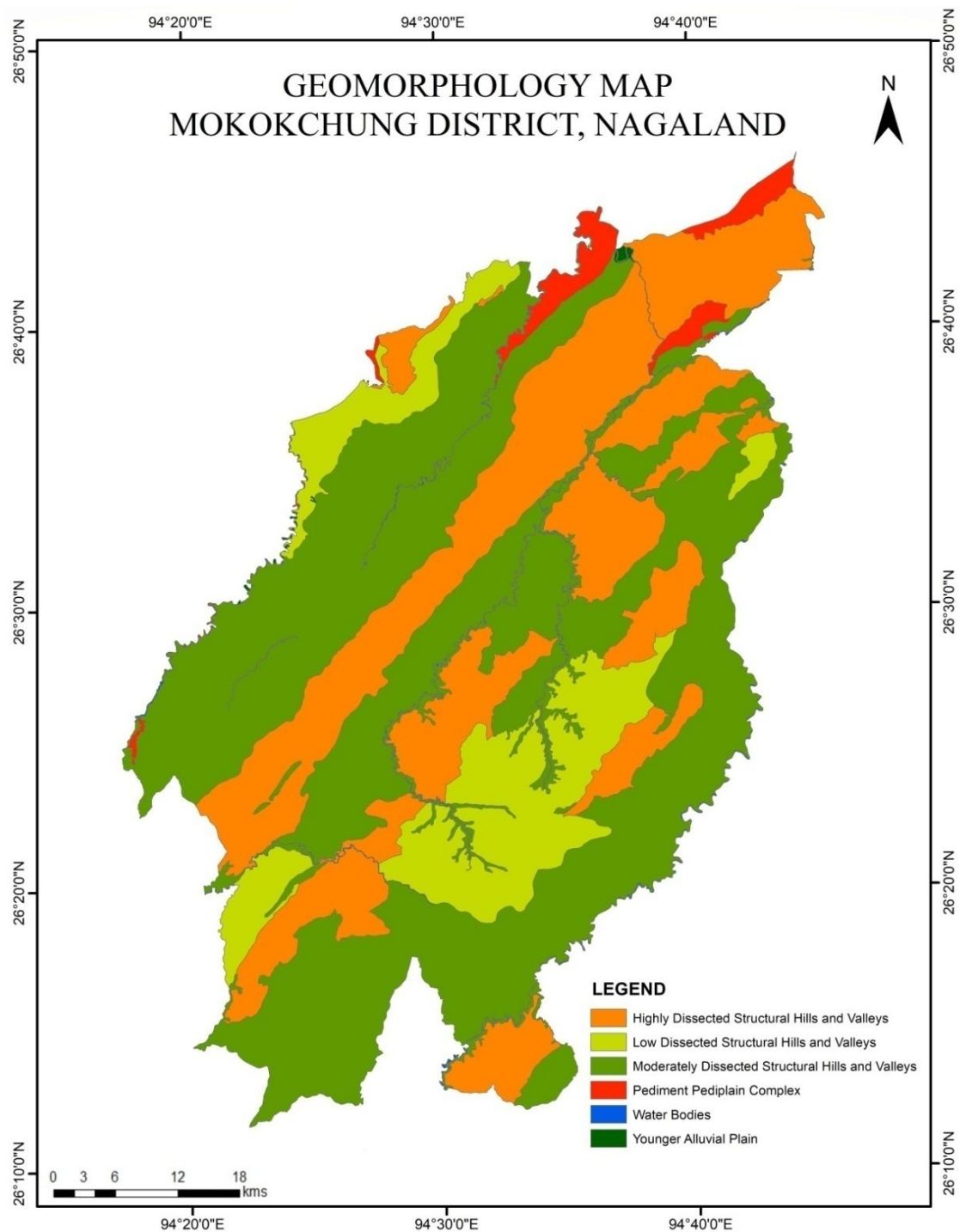


Figure 2.4: Geomorphological Map of Mokokchung District.

2.1.2.3. Low Dissected Structural Hills and Valleys: These areas are largely situated along the western and southern peripheries of Mokokchung district. It is characterized by gentle slopes ranging from 0° to 14° and is relatively subdued with broader valleys and lower elevations. These areas are notably more favourable for agriculture, supporting dense rural settlements and extensive cultivation. The underlying geology comprises mostly of softer sedimentary rocks as sandstones, claystones and siltstones, which are generally associated with the Surma and Tipam groups. These rock types promote enhanced weathering and soil formations.

2.1.2.4. Pediment Pediplain Complex: These areas are found intermittently along the district's margins, particularly in the southwest and northwest. These transitional zones lie between elevated terrains and valley floors, formed through gradual erosional and depositional processes. These gently sloping surfaces are composed of weathered rock and alluvial deposits, providing relatively fertile soils which are well suited for agriculture.

2.1.2.5. Younger Alluvial Plains: These areas occur as narrow, linear tracts along major river valleys, especially in the eastern part of the district. These flat, fertile plains are formed by recent deposition of fluvial sediments, consisting of unconsolidated materials such as sand, silt and clay. This region supports intensive agriculture and often corresponds with areas of high population density.

2.1.3. Geology

The geology of Nagaland (Figure 2.5) forms part of a relatively young and tectonically active belt, representing the northern extension of the Indo-Myanmar range. Bounded by the Arunachal Himalaya in the north and stretching southward toward the Andaman and Nicobar Islands, the Naga Hills mark the northernmost segment of this structural framework, terminating at the Mishmi Hills (Soibam, 1998). Geologically, the region is highly complex both tectonically and structurally, and is longitudinally grouped into three units based on major morphotectonic elements: the Belt of Schuppen, the Inner Fold Belt, and the Ophiolite Complex (Directorate of Geology & Mining, 1978).

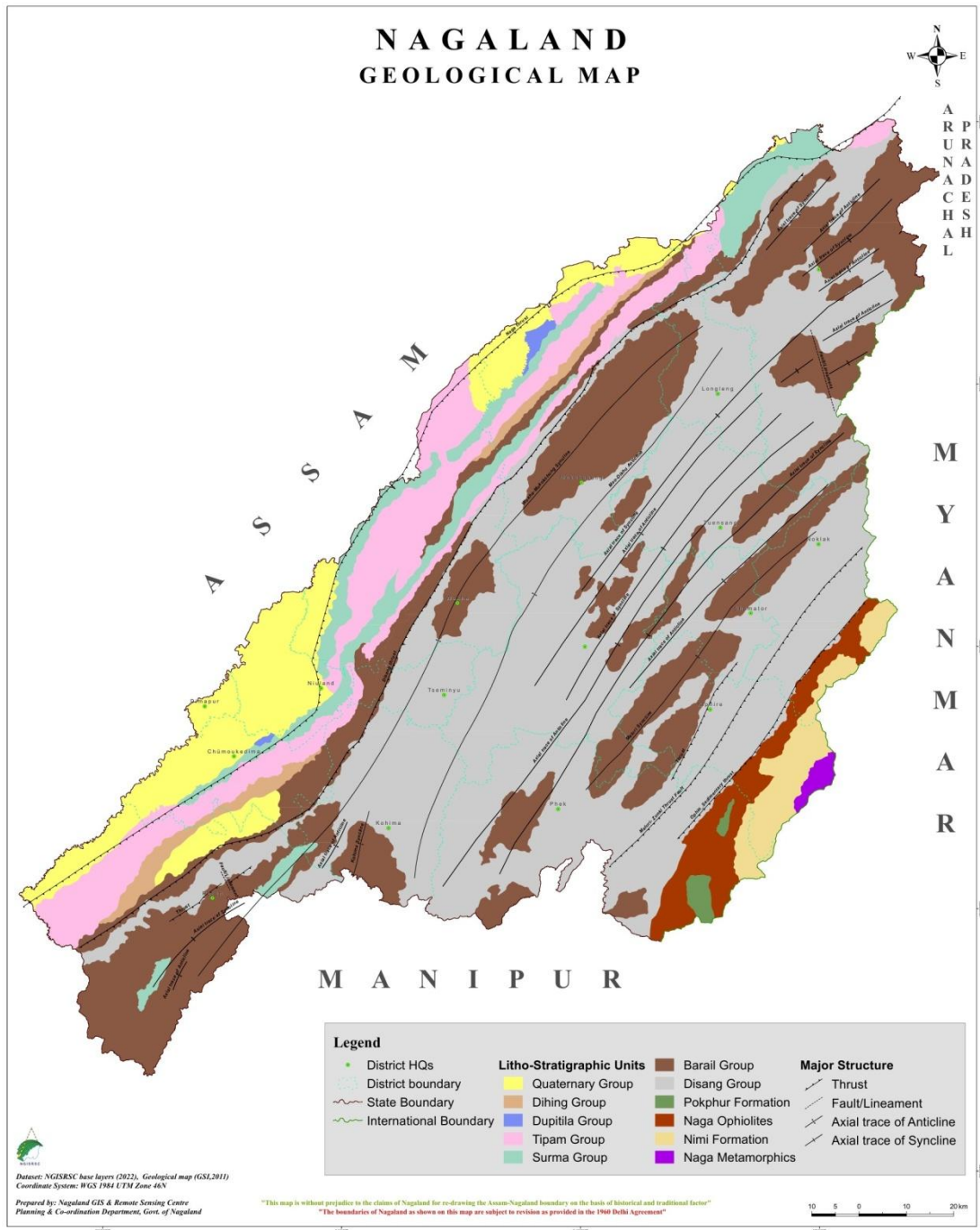


Figure 2.5: Geological Map of Nagaland (Source: NGISRSC, 2022).

The geology of Mokokchung District (Figure 2.6) is largely depicted by its location in the Eastern Himalayan region which is characterized by a complex geological history. The geological framework of Mokokchung district, located in the northern part of Nagaland, is defined by a complex sequence of sedimentary formations belonging to the Tertiary period. These formations are part of the Indo-Myanmar geosynclinal belt and illustrate the dynamic tectonic activity that has shaped the region over time.

The rock sequence in Mokokchung comprises distinct litho-stratigraphic units. It begins with the Disang Group, dating to the Lower and Middle Eocene, followed by the Barail Group of Upper Eocene to Oligocene age. This sequence is subsequently overlain by the Surma and Tipam Groups, both assigned to the Miocene epoch. Additionally, the sequence includes the Namsang beds, representing the Mio-Pliocene age. These lithological formations observed in stratigraphic order across various geological sections of the region are as:

Table 2.1: Stratigraphy of Mokokchung District (Directorate of Geology and Mining, 1996)

Age	Geosynclinal sediments of Nagaland (and as such of Mokokchung District)	Thickness in Meters
Recent & Pleistocene	Alluvium and high level terraces -Unconformity-	-----
Pliocene	Dihing Group --Unconformity--	400
Mio-Pliocene	Namsang beds --Unconformity--	800 1800
Miocene	Tipam Group } Girujan clay } Tipam Sandstone Surma Group --Unconformity--	2300 900
Oligocene	Barail Group } Tikak Parba } Baragolai Naogaon	600 2300 2200
Eocene	Disang Group	3000

The region is characterized by a series of sub-parallel thrusts, arranged in an imbricate manner dipping in a south-easterly direction. The parallel traverse faults have affected the entire sequence resulting in a north-westerly shift of the Barail coal measures and the overlying Tipam sandstone. Moreover, the presence of minor reverse faults along hill crest has further deformed the Tipam units, complicating the structural features of the region (Geological Survey of India, 2011).

Table 2.2: Geological sequence of Mokokchung District (Directorate of Geology and Mining, 1996)

Older Alluvium Deposit	clay, coarse sand, gravel & boulder
Tipam Group	Tipam sandstones formation- Girujan clay formation
Surma Group	Surma sandstones formation
Barail Group	Barial sandstones formation
Disang Group	Disang shale formation

2.1.3.1. Disang Group: The Disang Group forms the oldest lithological unit in the district, estimated to be approximately 54 million years old. It comprises a monotonous succession of dark gray to black splintery shales, with thin silty and sandstone interbands, and occasional rhythmities. These rocks are extensively found in the western part of Mokokchung and significantly crumbled and deformed, making them structurally weak. Common features include quartz veins and scattered pyrite, indicating post depositional mineralization processes. Due to their fine grained structure and vulnerability to weathering, Disang rocks result in inadequate slope instability and are highly prone to mass movements and landslides (Geological Survey of India).

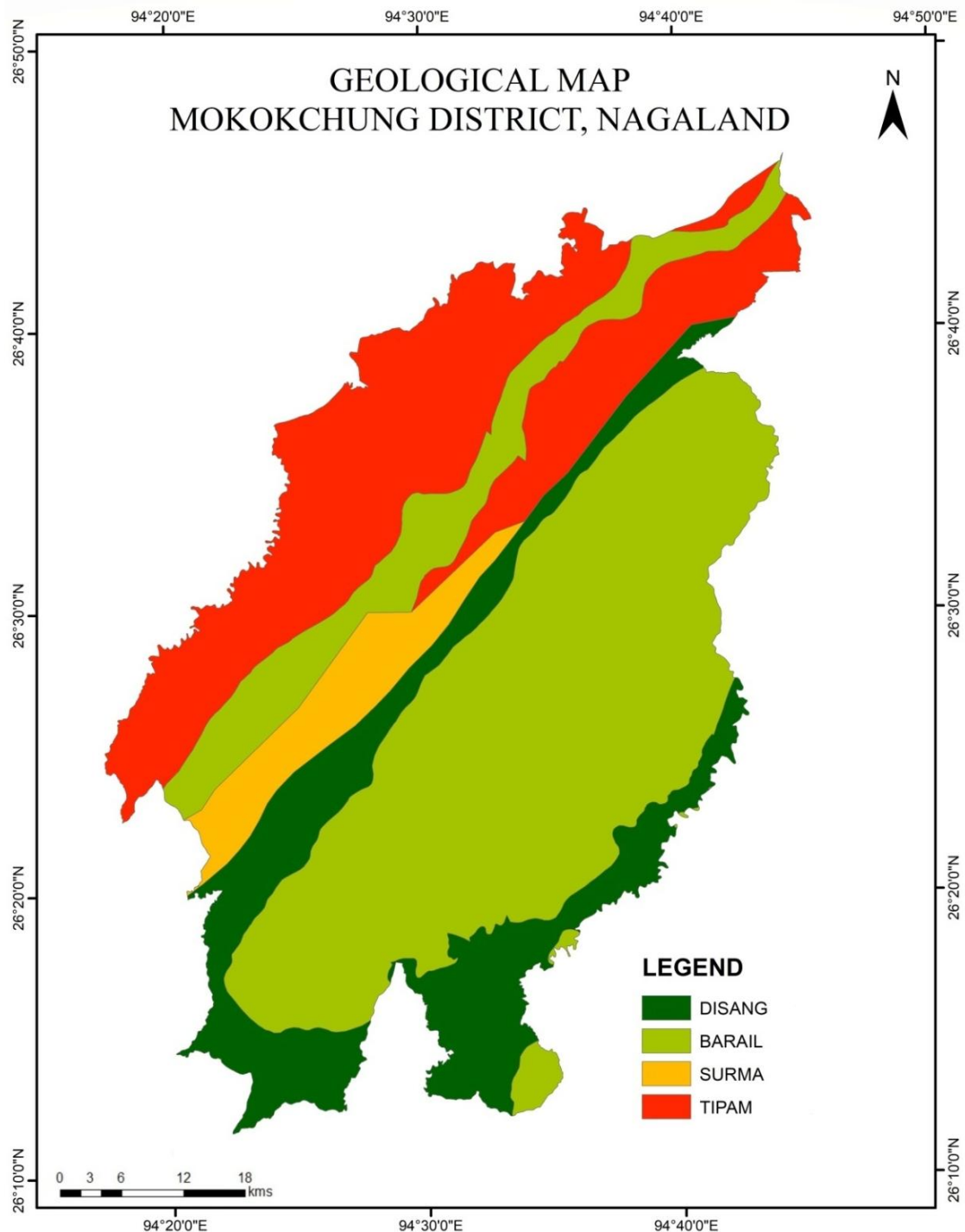


Figure 2.6: Geological Map of Mokokchung District.

2.1.3.2. Barail Group: Overlying the Disang Group, the Barail Group consists of a thick, well-bedded succession of sandstones and shales, frequently inter-layered with coal seams. Structurally, these coal bearing Barail formations commonly occur as sub-parallel thrust slices within the younger Tipam Group, reflecting the complex tectonic

setting of the region. The sandstones of this group are generally hard and ferruginous, and they often alternate with carbonaceous shales. Distinct bedding and lamination features are well developed, indicating deposition in a fluvio-deltaic environment. While these lithological characteristics provide valuable insights into the depositional history, they also contribute to slope instability in tectonically active regions, thereby posing significant challenges for land use planning and development of infrastructures. The Barail group is subdivided into three principal formations:

- i. The Naogaon formations, composed predominantly of well-bedded sandstones with intercalations of shales.
- ii. The Baragolai formations, consisting of alternating sandstones and shales with several coal seams.
- iii. The Tikak Parbat formation continues the lithological characteristics of earlier sequences, particularly distinguished by its thicker and more enduring coal seams.

2.1.3.3. Surma Group: The Surma Group originating from Miocene Epoch is composed of interbedded shale, sandstone and occasional conglomerates. This unit is characterized by a basal conglomerate horizon which varies in thickness from just a few centimeters to more than 13 meters. The diverse lithology ranging from fine sediments to coarse-grained deposits substantially affects permeability and mechanical strength, resulting in variable slope stability throughout the district. The variations in sediment type reflect periodic changes in depositional energy, most likely linked to fluvial and deltaic settings.

2.1.3.4. Tipam Group: The Tipam Group constitutes the youngest of the sedimentary successions in Mokokchung. It predominantly consists of thickly bedded, hard ferruginous sandstones intercalated with minor shales and siltstones. These sandstones frequently weather to a light brown hue and are typically exposed along the higher ridges of the district due to their resistance to erosion. The Girujan clay formations characterized by mottled blue and red clays, argillaceous sandstones, and grits can be found overlying the Tipam in specific regions. This unit is particularly well developed in the Desai River Valley, west of Changki. However, the Girujan clays are soft and

highly susceptible to water absorption, a characteristic that further diminishes slope stability and increases vulnerability to landslides.

2.1.4. Drainage

Nagaland, situated in northeastern India, is characterized by a diverse physiographic landscape of steep hills, deep valleys, and narrow intermontane plains. This complex terrain plays a vital role in shaping the region's hydrological behavior and river systems. The interaction of climate, relief, geological structure, and lithology has resulted in an extensive drainage network, reflecting the area's geological history and ongoing erosional processes. Understanding the drainage characteristics of any area is essential for assessing watershed development, water availability, and related geomorphological hazards. In Nagaland, the rugged mountainous terrain strongly influences the nature of its rivers, resulting in fast flowing streams that closely follow the structural controls of the landscape. These rivers not only shape the physical terrain but also have a significant impact on settlement patterns, agriculture, and livelihoods. The Barail and Japfu ranges, along with their extensions into the Mokokchung and Tuensang districts, act as an important watershed divide separating the Brahmaputra and Chindwin river systems. Most major rivers such as Doyang, Dhansiri, Dikhu, and Milak, flow westward and form part of the Brahmaputra basin. In contrast, the Tizu is the only river flowing eastward and eventually draining into the Chindwin river of Myanmar and further into the Irrawaddy system. The occurrence of both dendritic and parallel drainage patterns across the state as illustrated in Figure 2.7 indicates the influence of variations in topography, slope, and underlying geological structure.

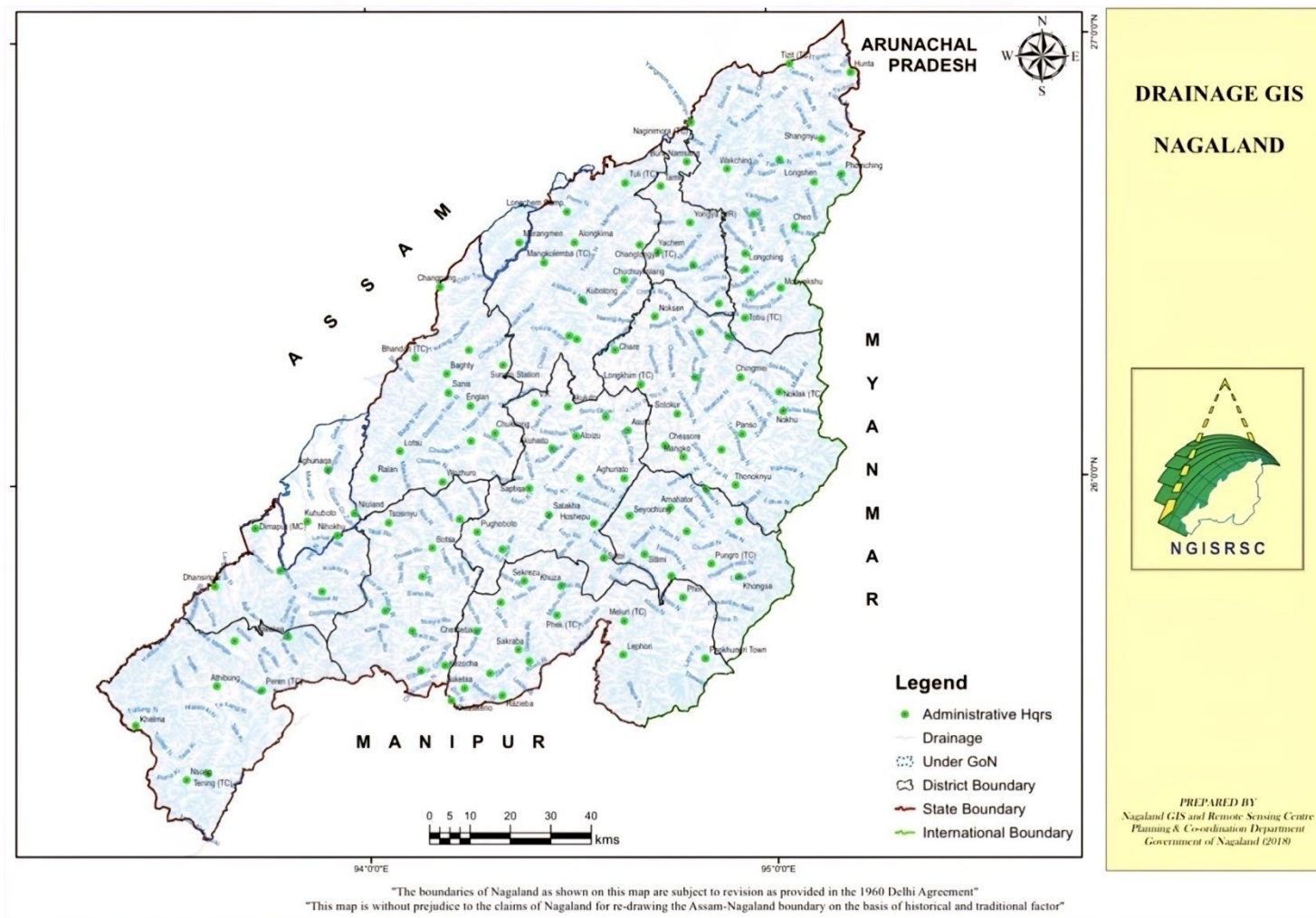


Figure 2.7: Drainage Map of Nagaland (Source: NGISRSC, 2018).

Mokokchung District of Nagaland is endowed with several rivers and streams that flow through the glens and gorges of the different ranges. A number of seasonal and perennial streams flow through the district. The rivers draining the district come under the Brahmaputra river system. Most of the rivers are perennial in nature but the volume keeps fluctuating (reduces during the dry season). Major rivers draining the district of Mokokchung are Milak, Dikhu, Tsurang and Menung (Figure 2.8).

2.1.4.1. Milak River: It is the main and longest river draining the district of Mokokchung. The Milak river has its source in the center of Mokokchung town and flows in a northerly direction till it reaches Tuli range where it takes a north-western direction adjoining the Assam plains and flowing through the Sibsagar district. An important tributary of Milak river is Tsurong.

2.1.4.2. Dikhu River: Dikhu river has its source near Zunheboto district, flowing westwards and entering Longsa village of Ongpangkong range. It flows in a northward direction which forms a traditional boundary between Mokokchung and Tuensang districts. It then flows further northward through the hills of Mon district and flows down to the Naganimora plains. Nanung is the main tributary of Dikhu.

2.1.4.3. Tsurang River: It originates in the west of Chungliyimsen village in Jangpetkong range and is an important tributary of Doyang river. It flows through the valley of Changki in a north to south direction near the boundary between Mokokchung and Wokha districts. It bends westward and then towards the north forming a crescentic bend and flows further until it enters the plains.

2.1.4.4. Menung River: It is the main tributary of Milak river. Menung river has its source from the Minkong forest which flows in between Sungratsu and Longjang village of Asetkong range on one side and Mongsenyimti and Chuchuyimlang village of Langpangkong range on the other and then ultimately joins Milak river.

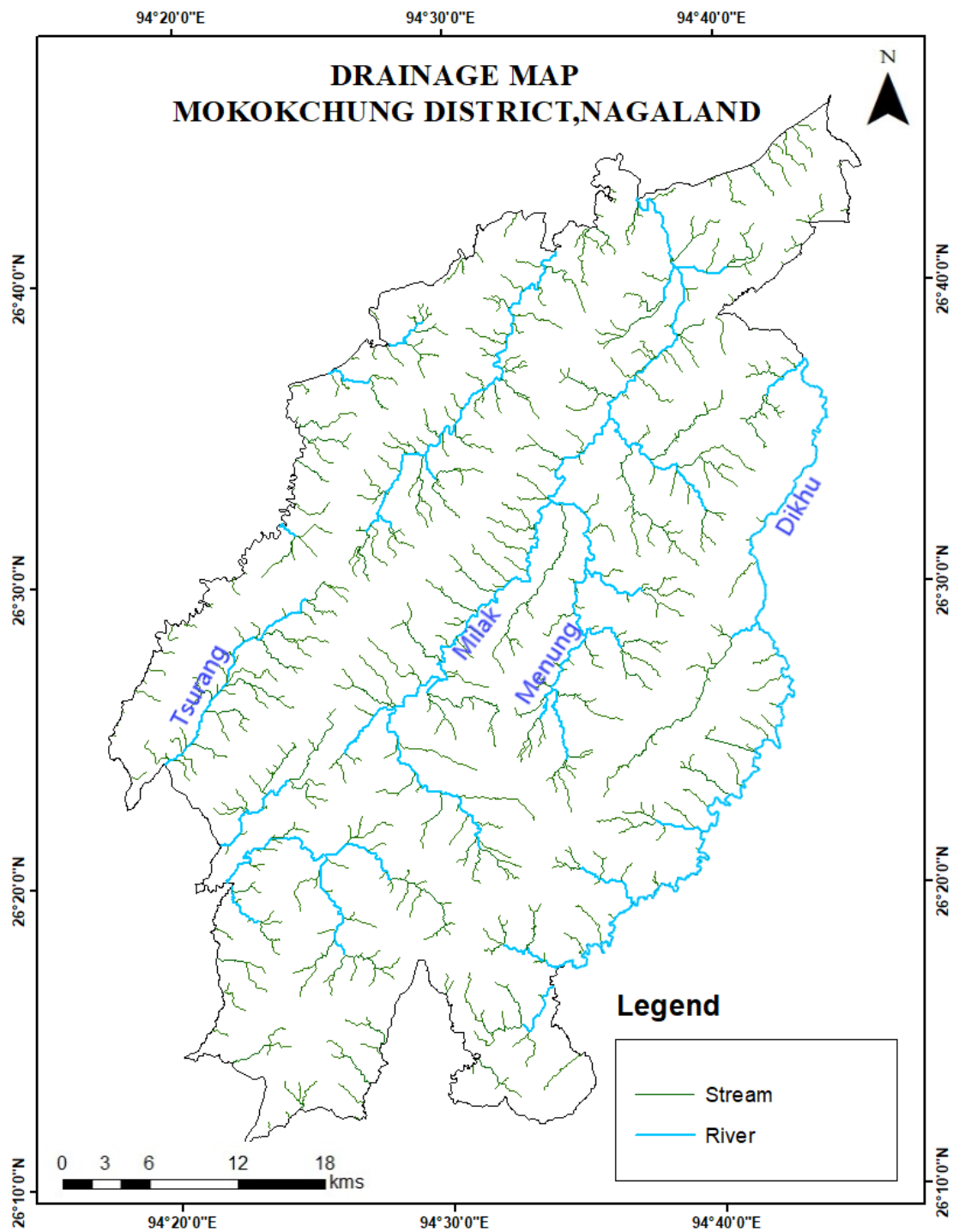


Figure 2.8: Drainage Map of Mokokchung District.

2.1.5. Climate

Climate refers to the long term pattern of atmospheric conditions in a region, including temperature, rainfall, humidity, and seasonal variations. Unlike weather, which describes short term and often rapidly changing atmospheric conditions, climate represent more stable and recurring patterns shaped by geographical location, topography, oceanic influences, and large scale atmospheric processes (Ahrens, 2019). Climate exerts a strong influence on both natural systems and human activities. It shapes distribution of vegetation, influences soil formation, and regulates hydrological cycles, thereby affecting biodiversity and overall ecological functioning (Barry & Chorley, 2010). A clear understanding of climatic conditions is therefore essential for assessing environmental hazards such as floods, landslides, droughts, and extreme weather events, particularly in regions characterized by complex terrain. In terms of increasing climate change, long term climate analysis has become increasingly important for sustainable development planning, disaster risk reduction, and informed policy making (IPCC, 2022).

Nagaland experiences a humid tropical climate, marked by a distinct monsoonal pattern, although local climatic conditions vary considerably due to differences in altitude and relief. The plain areas experience a warm subtropical climate, while the foothill zones with rolling and undulating terrain experience comparatively moderate subtropical conditions. Areas at low to moderate elevations, combined with varying slope gradients, experiences a sub-montane climate. The southwest monsoon mostly begins in during May and continues until September, with the highest rainfall usually recorded during July-September. The moisture index ranges between 40 and 60 percent, while annual rainfall averages between 1500 mm and 1800 mm during the months of May to October. The potential evapotranspiration is approximately 1219 mm.

Mokokchung District located at an average altitude of 1319 meters above mean level witnesses sub-tropical humid type of climate. It is largely influenced by its geographical location, topography and the monsoon winds. Unlike the adjoining plains of Assam, most parts of Mokokchung experiences cold winter and mild summer.

Basing on the seasonal climatic variations over the course of the year, two distinct seasons usually dominate the district of Mokokchung i.e. Winter and Monsoon. Spring and Autumn are however nominal and short lived. Winter season mostly starts by the month of November and lasts till February. The winter months are usually cold and dry. The temperature can drop significantly, varying from 6°C to 15°C. January is mostly the coldest month. Towards the end of winter, in the months of February and March, windy season takes place. During this time, the wind generally blows from the South-West and at times the velocity rises even up to 100km/hr causing damages to houses and trees. The wind gradually fades by the month of April. The month of May usually witnesses the pre-monsoon season when several showers are received. The month of June marks the onset of rainfall caused by the South-West monsoon and lasts till September. This period is characterized by heavy rainfall and high humidity, resulting in persistently damp conditions. During the monsoon season, the average relative humidity remains around 80% but it may occasionally rise to as high as 95%. Annual rainfall varies greatly from year to year ranging from 1500 mm to 2500 mm. To examine climatic variability and seasonal trends in the study area, records of temperature, humidity and rainfall of Mokokchung District covering a period of 11 years were collected from the Department of Soil and Water Conservation, Mokokchung which were subsequently analyzed to assess the prevailing climatic conditions of the region.

2.1.5.1. Annual Rainfall: During the period of 11 years (2012-2022), Mokokchung District received the highest amount of rainfall in the year 2018 with an annual rainfall of 2330.9 mm. The amount of rainfall varies greatly from year to year, the lowest and highest being 1410.9 mm and 2330.9 mm respectively (Figure 2.9).

2.1.5.2. Temperature: The average annual temperature of Mokokchung varies widely, ranging from about 28°C during the summer months to 6°C in winter. Temperature begins to rise from May, reaching their peak during July and August, which represent the warmest months of the year. Temperature of Mokokchung district recorded the highest in the year 2021 with an average maximum of 32.64°C in the

month of August and recorded the lowest in the year 2016 with an average minimum temperature of 6.0°C in the month of January.

2.1.5.3. Relative Humidity: The average relative humidity of Mokokchung District indicates high moisture content in the order of 60% and 80%. The highest was recorded in the year 2019 and lowest in the year 2014 with an average relative humidity of 78.46% and 62.34% respectively.

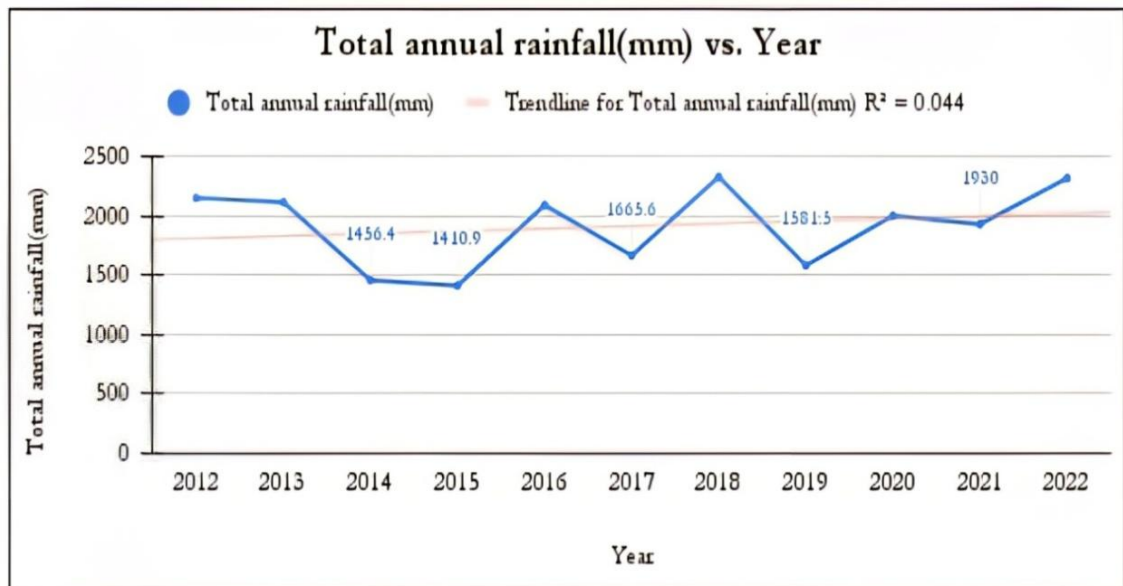


Figure 2.9: Average annual rainfall of Mokokchung District.

Table 2.3: Annual and monthly maximum, minimum and average temperature (in °C) of Mokokchung District during 2012-2022
(Source: Directorate of Soil and Water Conservation, Mokokchung, Nagaland).

Year		J	F	M	A	M	J	J	A	S	O	N	D	Average
2012	Max	18.84	22.80	25.19	26.0	28.42	28.23	28.32	28.23	27.57	26.29	23.03	20.03	25.24
	Min	6.65	8.27	10.92	14.27	17.81	19.8	21.16	20.77	19.83	16.81	11.03	7.87	13.94
2013	Max	20.77	23.5	26.61	27.37	26.77	28.6	27.03	27.75	27.89	26.24	24.21	19.51	25.52
	Min	6.13	8.61	10.13	13.27	17.32	20.47	21.13	21.26	20.82	17.68	11.52	6.88	14.60
2014	Max	19.90	22.11	24.98	28.85	28.77	27.63	28.16	27.25	27.58	26.73	24.18	20.93	25.59
	Min	6.79	7.54	9.6	14.49	17.24	20.51	21.07	21.30	20.67	17.51	12.97	9.86	14.96
2015	Max	20.15	21.15	24.89	24.7	26.72	26.9	27.1	26.2	26.2	26.3	20.7	16.9	23.90
	Min	7.53	7.52	11.50	13.88	17.38	20.8	21.1	20.8	21.0	19.5	14.4	6.8	15.18
2016	Max	17.81	19.14	21.9	24.45	25.43	26.16	26.12	27.49	26.0	25.77	18.73	15.60	22.86
	Min	6.0	11.6	15.3	17.1	17.5	19.9	19.6	20.7	19.9	19.4	14.2	10.3	15.95
2017	Max	13.21	17.44	17.87	18.12	19.0	23.58	25.67	26.56	25.42	23.53	19.09	19.05	20.77
	Min	6.5	8.5	10.9	13.2	14.4	15.9	18.5	21.1	21.50	18.8	13.7	17.2	15.01
2018	Max	15.32	15.44	22.56	25.44	25.56	26.88	27.06	26.63	26.23	24.48	22.0	18.6	22.91
	Min	9.6	7.50	10.55	12.3	14.4	17.80	19.69	20.42	20.4	16.0	12.9	11.2	14.39
2019	Max	16.9	17.34	20.5	24.6	26.45	27.45	27.15	28.47	27.67	22.85	21.35	15.8	23.01
	Min	8.1	8.6	13.4	18.8	18.0	14.2	19.2	19.57	18.33	15.04	14.58	11.0	14.90
2020	Max	14.4	15.4	19.48	22.61	23.45	24.80	24.56	25.43	22.71	23.13	19.76	17.6	21.11
	Min	8.0	8.9	12.50	15.43	16.20	17.11	17.36	17.65	17.34	15.62	12.14	9.0	13.93
2021	Max	14.9	14.86	20.82	25.51	24.75	32.64	25.25	27.04	27.99	27.00	23.21	19.13	25.27
	Min	7.4	7.61	11.09	14.23	14.53	18.50	18.88	20.40	21.12	18.81	14.04	9.6	14.68
2022	Max	14.13	15.96	19.74	24.47	25.87	31.02	24.67	28.12	26.75	26.05	22.14	18.07	23.08
	Min	7.2	7.32	10.78	13.87	14.45	18.67	18.6	20.09	20.98	18.34	13.85	9.37	14.46

Table 2.4: Average monthly and annual humidity (R/H in 5%) of Mokokchung District during 2012-2022

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

Year	J	F	M	A	M	J	J	A	S	O	N	D	Average
2012	62.29	63.13	61.25	62.86	61.94	62.93	81.23	78.39	75.93	69.84	62.0	61.29	66.92
2013	61.61	60.71	62.23	65.4	65.84	71.1	80.87	79.52	76.13	69.84	62.4	61.94	68.13
2014	62.81	62.0	60.68	61.5	61.90	67.3	76	81	74.7	60.93	43.06	36.29	62.34
2015	36.67	34.39	36.74	58.33	71.58	84	82	82	84	85	74	65.7	66.20
2016	66	67.4	60	69.9	71	82	87	83	84	83	79	73.8	75.50
2017	67.3	64	69	80	76	80	68	78	80.23	79	78	75.8	74.61
2018	76	46.07	33.54	33.7	52.4	71.2	79.70	77.80	84.2	76.48	72.3	69	64.28
2019	76.1	79.7	79.5	81.3	78.96	79.73	76.35	77.25	74.43	74.32	81.2	82.7	78.46
2020	77.74	78.68	78.03	76.03	78.709	74.16	78.25	74.41	80.6	80.58	78.23	71.90	77.27
2021	61.74	57.57	64.29	68.1	67.58	79.46	82.83	81.51	80.1	78.74	71.9	65.96	71.64
2022	75.24	61.7	65.03	66.25	69.30	74.54	80.34	81.71	80.4	76.53	69.8	63.92	72.06

Table 2.5: Annual and monthly total rainfall (in mm) of Mokokchung District during 2012-2022

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

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total annual rainfall(mm)
2012	74.8	0	38.8	240.4	121.9	284	484.1	431.2	320.7	146.5	9.4	0	2151.8
2013	0	18.7	86.5	118.9	570.2	349.5	411.9	348.3	123.4	76.8	0	12.4	2116.6
2014	19.1	21.7	33.6	41.3	67.7	174.7	407.1	326.8	311.7	50.5	2.2	0	1456.4
2015	29.2	25.4	10.4	204.3	112.9	269.7	354.2	29.7	263.7	75.2	23.3	12.9	1410.9
2016	8.3	34.2	72	284.3	224.4	289.1	436.1	405	259.3	57	13.3	8.4	2091.4
2017	9.0	19	131.8	177.5	160.4	268.4	272.3	146	232.8	203.6	22.6	22.2	1665.6
2018	28.2	15.7	41.4	109.7	405.2	383.6	618.8	458.9	123.6	74.6	17	54.2	2330.9
2019	4.3	41.2	67.1	146.6	165.5	238	464	148.9	302.2	205.3	98.4	0	1581.5
2020	45.6	19.4	30.8	186.8	192.4	431.4	249.1	276.1	242.9	239.8	85.2	3.2	2002.7
2021	4	6	66.7	53.5	251.4	382.9	409	315	363.8	63.9	0.2	13.6	1930
2022	17.4	9.9	98.3	168	214	413.3	604.7	439.2	342.7	87.5	15.6	2.9	2319.8

2.1.6. Natural Vegetation

Natural vegetation develops largely without direct human intervention and is shaped by a combination of climatic conditions, soil properties, altitude, and other environmental factors (Odum & Barrett, 2005). The distribution of different vegetation types such as forests, grasslands, shrubs, and other native plant species reflects the ecological balance of a region and their long term adaptation to local environmental conditions (Singh, 2002). In Mokokchung district, the natural vegetation is dominated by subtropical evergreen rainforests and coniferous forests. These forest types are closely linked to the area's high humidity and prolonged rainfall. The district comprises six distinct hill ranges, each exhibiting subtle variations in terrain, soil, and microclimate. Such variations play an important role in shaping patterns of biodiversity across the landscape. Prominent tree species commonly found in these forests are Rhododendron, Oak, Birch, and Juniperus. Differences in altitude and physiography further contribute to the rich and diverse plant life observed throughout the district. Bamboo forests also constitute a significant component of Mokokchung's forest cover. They occupy approximately 7.52 percent of the district's total area, with species such as Bambusa tulda and Dendrocalamushamiltonii.

Table 2.6: Forest Cover Classification of Mokokchung District.

Sl. No.	Aspects	Assessment of 2019 (area in km ²)
1.	Total Geographical Area	1615
2.	Very Dense Forest	1.89
3.	Moderately Dense Forest	501.89
4.	Open Forest	823.83
5.	Total Forest Cover	1327.61
6.	Percentage of GA	82.20
7.	Change	5.61
8.	Scrub	22.08

Source: India-State of Forest Report 2019, Forest Survey of India.

According to the State of Forest Report 2019, published by the Forest Survey of India, Mokokchung District has a forest cover of 1327.61 km², accounting for approximately 82 percent of its total geographical area of 1615 km² (Table 2.6). A comparison with earlier assessments indicates a gradual decline in forest cover; in the 2013 report, forest cover accounted for 84.21 percent of the district's area. With respect to density of canopy, the district comprises 1.89 km² of very dense forest, 501.89 km² of moderately dense forest, and 823.83 km² of open forest.

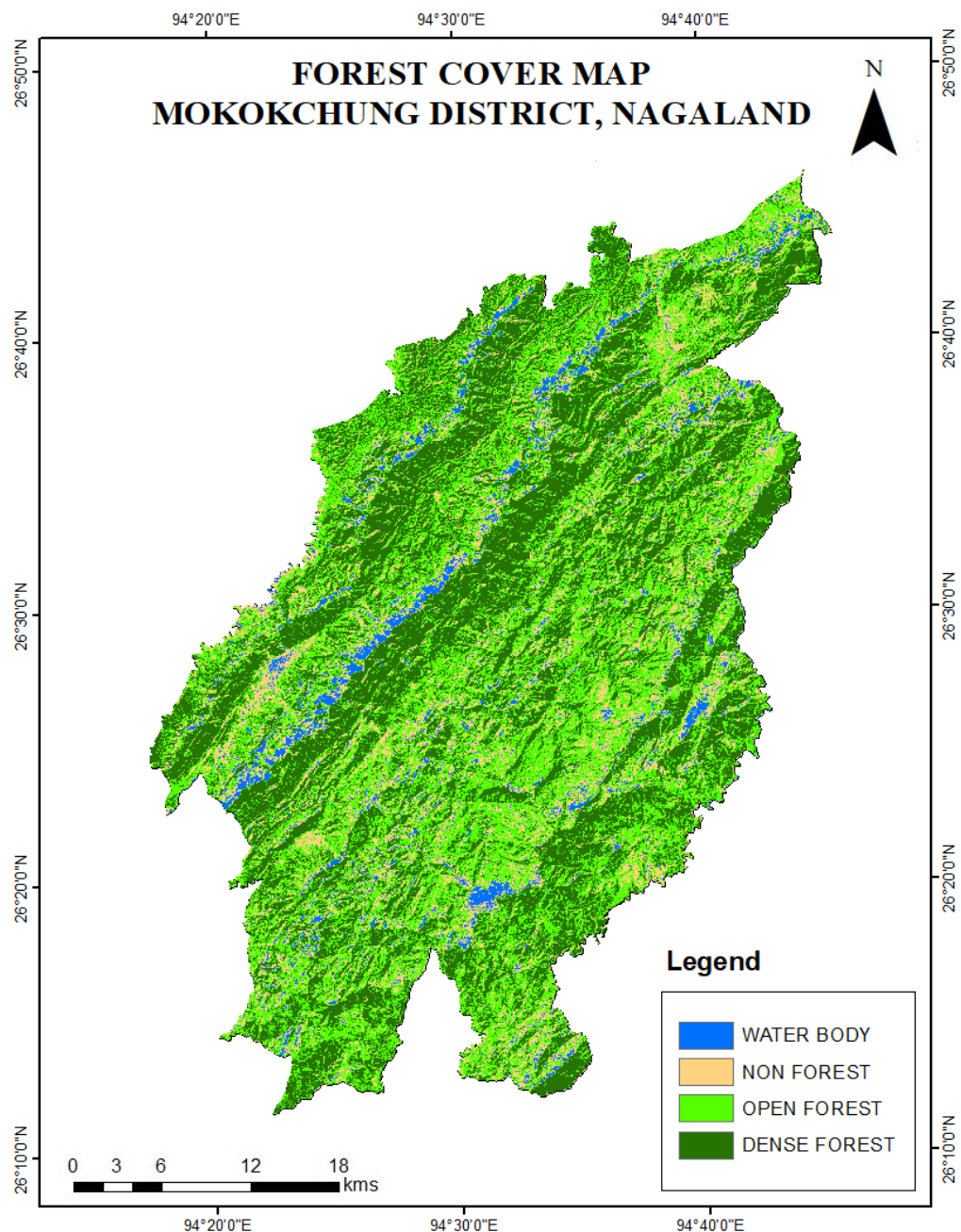


Figure 2.10: Forest Cover Map of Mokokchung District.

2.2. Human Geography

Human geography is the study of people and their social groups, cultures, and economic as well as their spatial and temporal relationships with the environment. Understanding the human geography of a region is essential for interpreting its cultural landscape, demographic characteristics, and socio-economic patterns, especially in areas experiencing environmental or developmental changes. It also plays a major role in determining the occurrence and impact of geomorphological hazards. Patterns of settlements, land use practices, cultural traditions, and economic activities can either mitigate or exacerbate community vulnerability to hazards such as landslides, soil erosion, and floods (Smith, 2013). In regions where agriculture, particularly shifting cultivation or extensive slope farming is common, vegetation clearance and soil disturbance tend to accelerate slope instability and increase the risk of mass movements (Walker & Shiels, 2013). Likewise, population concentration in steep, geomorphologically weak areas often linked to traditional settlement patterns or land scarcity increase vulnerability to such hazards. Development of infrastructures such as roads, terraces, and expansion of urban areas can further alter the drainage networks and terrain, triggering slope failures or altering runoff patterns (Goudie, 2018).

2.2.1. Migration and Settlement

The migration and settlement history of the Ao Nagas is both complex and deeply rooted in oral traditions. According to Ao narrations, their ancestors initially resided in Longtrok, meaning “six stones”, located in present day Chungliyimti, an area inhabited by the Sangtam Nagas. Oral narratives describe their life in Chungliyimti as peaceful and flourishing, a period marked by cultural advancements. However, population growth compelled the Ao to seek more fertile lands. They employed indigenous techniques to evaluate soil fertility, such as digging a pit and refilling it to assess quality of soil for agriculture and settlement. This exploration eventually directed them towards the west across the Dikhu river, where they established the village of Soyim in the fertile Aonglenden valley. This stay at Soyim however was short-lived due to an unfortunate incident, resulting in fragmentation of the settlement. Some moved to Koridang, while others settled at the old site and

renamed it Ungma. From these early centers, the Ao expanded across the six mountain ranges of present day Mokokchung district, establishing several other villages. This migration pattern not only determines their territorial distribution but also influenced the cultural and socio-economic identity of the Ao community.

2.2.2. Spatial Distribution and Density of Population

The demographic composition and spatial distribution of Mokokchung district illustrate a dynamic interaction of topography, land-use pattern and infrastructural accessibility. These factors influence the distribution of population and reflect both natural and socio-economic determinants. According to 2011 Census, the district is administratively divided into nine circles. Ongpangkong accounts for the largest population share at 43.03%, followed by Tuli (12.01%), Chuchuyimlang (9.16%), Changtongya (9.16%), Mangkolemba (6.65%), Kubolong (6.51%), Alongkima (6.13%), Longchem (4.42%), and Merangmen (3.10%), respectively as depicted in Table (2.7) and Figure (2.11). The population density in Mokokchung district differs considerably, ranging from 196 persons per km² in Ongpangkong circle to 38 persons per km² in Longchem circle. Additionally, the population densities in the other circles are: Tuli-132 persons per km², Chuchuyimlang-108 persons per km², Changtongya-156 persons per km², Mangkolemba-55 persons per km², Kubolong-109 persons per km², Alongkima-52 persons per km², Merangmen- 46 Persons per km², and Longchem-38 Persons per km² respectively (Table 2.7).

Table 2.7: Circle-wise population distribution and density of Mokokchung district, Nagaland, 2011 (Source: District Census handbook Mokokchung, 2011).

Circles	Population (2011)	Percentage of total population	Population Density
Ongpangkong	83,797	43.03	196
Chuchuyimlang	17,832	9.14	108
Mangkolemba	12,957	6.60	55
Kubolong	12,679	6.50	109
Alongkima	11,947	6.09	52
Tuli	23,377	12.01	132
Changtongya	17,832	9.12	156

Longchem	8617	4.41	38
Merangmen	6044	3.10	46
Total	1,94,622	100	120

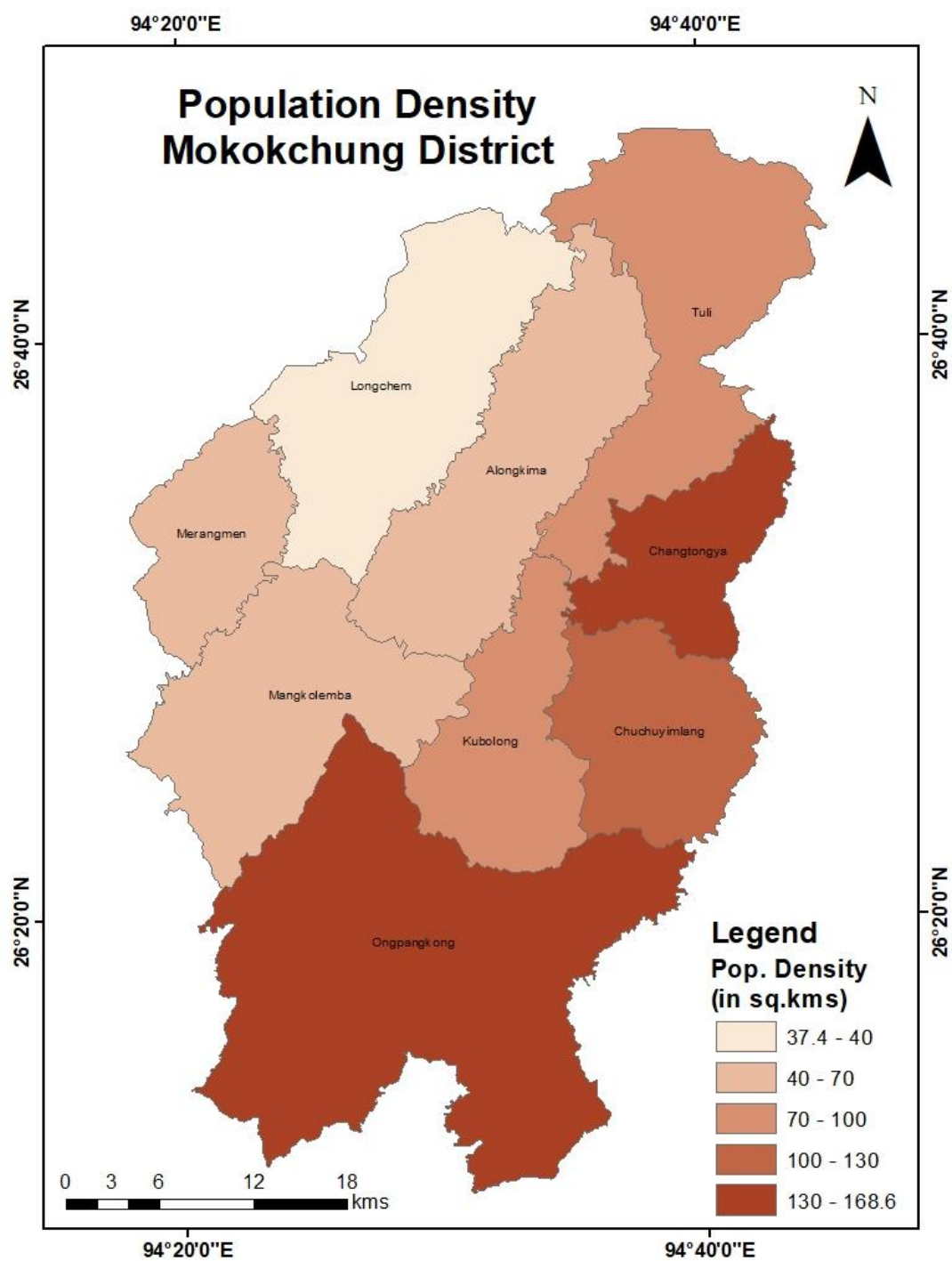


Figure 2.11: Population Density Map of Mokokchung District.

2.2.3. Temporal Variability of Population

It has been done so by analyzing the demographic trends and shifts in population characteristics in Mokokchung district over the decade, by assessing changes between the 2001 and 2011 Census data, allowing for a clear understanding of the district's population dynamics, including growth trends, spatial distribution, and socio-economic implications. Unlike many districts in India that experienced population growth, Mokokchung recorded a negative population growth rate between 2001 and 2011, ranging from -2.18% in Ongpangkong to -42.04% in Mangkolemba (Table 2.8). However, it is essential to consider that Merangmen circle was carved out of Mangkolemba after the 2001 Census. If the 2011 population figures for the two circles are combined for the comparison, the decline rate would be less pronounced. Notably, Longchem (-33.57%), Alongkima (-29.56%), Changtongya (-26.26%), and Kubolong (-38.71%) circles recorded population declines exceeding 20% during the decade. Among the various factors contributing to the decline in population, two significant developments may be noted i.e., the detailed and systematic enumeration carried out during the 2011 Census, and the campaign led by the Ao Students' Conference in 2002, conducted under the banner "Survival Mokokchung" which aimed to identify and expel illegal immigrants from the district.

Table 2.8: Decadal population variation of Circles, Mokokchung district, Nagaland, 2001-2011 (Source: District Census handbook Mokokchung, 2011).

Circles	Population (2001)	Population (2011)	Decadal variation %
Mangkolemba	22,356	12,957	-42.04
Kubolong	20,686	12,679	-38.71
Alongkima	16,960	11,947	-29.56
Changtongya	23,560	17,832	-26.26
Chuchuyimlang	22,149	17,832	-19.49
Tuli	27,735	23,377	-15.71
Ongpangkong	85,667	83,797	-2.18
Longchem	12972	8617	-33.57
Merangmen	-	6044	0
Total	23,2085	1,94,622	-16.14

2.2.4. Rural-Urban Population Structure

As per the Census of 2011, Mokokchung district has a population structure that is mainly rural, with a significant proportion of its inhabitants residing in villages. Out of the total population of 194,622, approximately 71.37% live in rural areas, while the remaining 28.63% are concentrated in urban centers, primarily in the district headquarters of Mokokchung town, Tuli and Changtongya circles (Table 2.9). The urban population, though smaller in proportion, has shown gradual growth due to increasing migration for education, employment, and access to better services.

Table 2.9: Rural and urban composition of population in Mokokchung district, 2001-2011 (Source: District Census handbook Mokokchung, 2022).

Circles	Rural	Urban	Total
Ongpangkong	47,884	35,913	83,797
Chuchuyimlang	17,832	-	17,832
Mangkolemba	12,957	-	12,957
Kubolong	12,679	-	12,679
Alongkima	11947	-	11947
Tuli	11097	12280	23,377
Changtongya	9840	7532	17,832
Longchem	8617	-	8617
Merangmen	6044	-	6044
Total	13,8897	55,725	19,4622
	71.37%	28.63%	100%

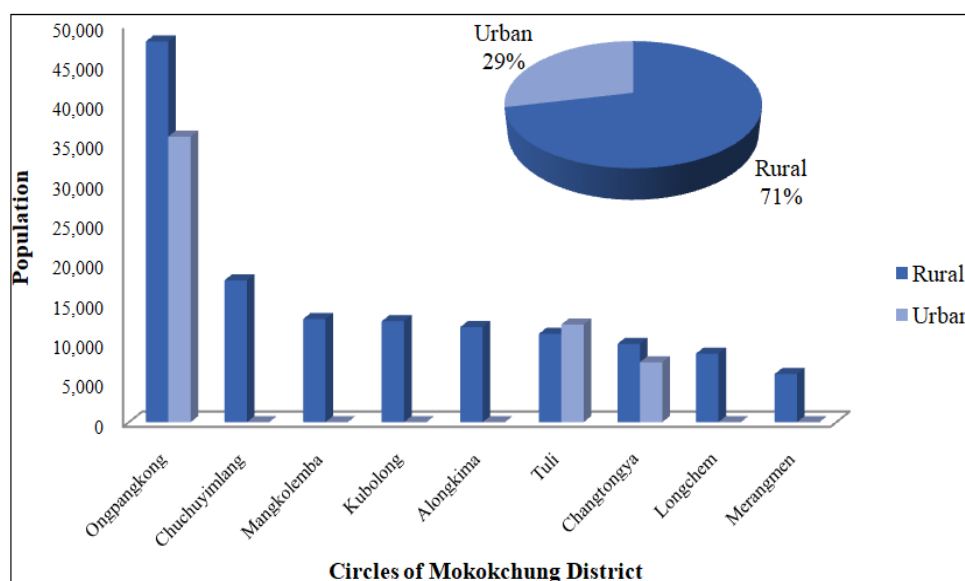


Figure 2.12: Rural and urban composition of population in Mokokchung district, Nagaland, 2001-2011.

2.2.5. Literacy

As per the 2011 Census, Mokokchung district demonstrated a notable literacy rate of 91.62%, substantially exceeding the state average of 79.55%. A notable aspect of Mokokchung's literacy profile is the minimal gender disparity. Male literacy rate stands at 92.18% while female literacy rate closely stands at 91.01% indicating a gender gap of merely 1.17%. Among the administrative circles, Changtongya records the highest literacy rate at 95.4% closely followed by Alongkima with 95.29%. Out of the nine circles in the district, six circles have reported literacy rate exceeding 90% reflecting a consistently high level of educational attainment across Mokokchung (Table 2.10).

Table 2.10: Literacy rate by sex in circles of Mokokchung District, 2011
(Source: District Census handbook Mokokchung, 2011).

Sub-Districts	Literacy Rates		
	Male	Female	Average
Ongpangkong	93.49	92.56	93.04
Chuchuyimlang	91.59	91.44	91.52

Mangkolemba	87.91	85.55	86.74
Kubolong	91.11	88.9	90.04
Alongkima	96.46	94.31	95.39
Tuli	90.5	88.2	89.46
Changtongya	95.79	94.99	95.4
Longchem	92.06	90.62	91.35
Merangmen	74.6	75.09	74.82
District: Mokokchung	92.18	91.01	91.62

2.2.6. Economy and Occupational Structure of Mokokchung District

As per 2011 Census, out of the total population of 19462, a total of 10067 persons (51.42%) are classified as workers, indicating that for every 1000 persons, approximately 514 are in the working population, while 486 are non-workers.

2.2.6.1. Main workers

Defined as those engaged in economically productive activity for the most part of the reference year, main workers constitute 81,046 individuals, or 41.64% of the total population, at the sub-district level. Chuchuyimlang circle records the highest main work participation rate at 51.75% followed by Alongkima at 47.89%. The lowest rate is observed in Ongpangkong circle, where only 38.16% of the population is engaged as main workers.

2.2.6.2. Marginal workers

Individuals who worked for less than six months of the reference years are termed as marginal workers and they constitute 9.77% of the district's total workers. In absolute terms, this indicates a significant portion of the workforce engaged in part time or seasonal employment. Among administrative circles, Longchem reports the highest marginal work participation rate, at 21.99% followed by Merangmen at 17.64%. The lowest rate is recorded in Ongpangkong at 6.08%, a pattern consistent across both male and female marginal workers.

2.2.6.3. Non-workers

Approximately 48.58% of the district's total population was classified as non-workers. This category involves all individuals who did not participate in any income generating activity during the reference period, including students, dependents, homemakers, the elderly and persons with disabilities. The non-working population includes a significant number of females, many of whom may engaged in unpaid domestic or subsistence activities not counted within the formal economic framework. Moreover, the relatively high percentage of non-workers in certain circles, such as Ongpangkong, which also records the lowest work participation rate (44.24%) further underscores the uneven distribution of labour force participation across the district.

2.2.6.4. Economic Activity

The economic activity of the working population in Mokokchung district is classified into four major categories: Agricultural labourers, cultivators, household industry workers and other workers (Figure 2.13). This classification reflects the broader structure of the district's economy, which remains largely agrarian in nature. As per the 2011 Census, the total workforce comprising both main and marginal workers is distributed across these categories in varying proportions. Cultivators form the largest occupational group, with 48,925 individuals engaged in this activity. Agricultural labourers account for 9166 individuals. Combined, these two groups represent 58.05% of the total workforce, indicating the dominant role of agriculture and its allied activities in the district's economy. Workers engaged in household industries represent 3.80% of the total and other workers include those employed in sectors such as government services, private enterprises, transport and trade, constitute 38% of the total work population.

Table 2.11: Occupational structure of population in Mokokchung district, Nagaland
(Source: District Census handbook Mokokchung, 2011).

Sub-Districts	Total Population	Total Workers		Main Workers		Marginal workers		Non-workers	
		Number	%	Number	%	Number	%	Number	%
Ongpangkong	83,797	37075	44.24	31977	38.16	5098	6.08	46722	55.76
Chuchuyimlang	17,832	11142	62.48	9233	51.78	1909	10.71	6690	37.52
Mangkolemba	12,957	7317	56.47	5208	40.19	2109	16.28	5640	43.53
Kubolong	12,679	7922	62.48	6058	47.78	1864	14.70	4757	37.52
Alongkima	11,947	6887	57.65	5721	47.89	1166	9.76	5060	42.35
Tuli	23,377	12015	51.40	9695	41.47	2320	9.92	11362	48.60
Changtongya	17,832	8231	47.38	6637	38.21	1594	9.18	9141	52.62
Longchem	8617	5850	67.89	3955	45.90	1895	21.99	2767	32.11
Merangmen	6044	3628	60.03	2562	42.39	1066	17.64	2416	39.97
Total	194622	100067	51.42	81046	41.64	19021	9.77	94555	48.58

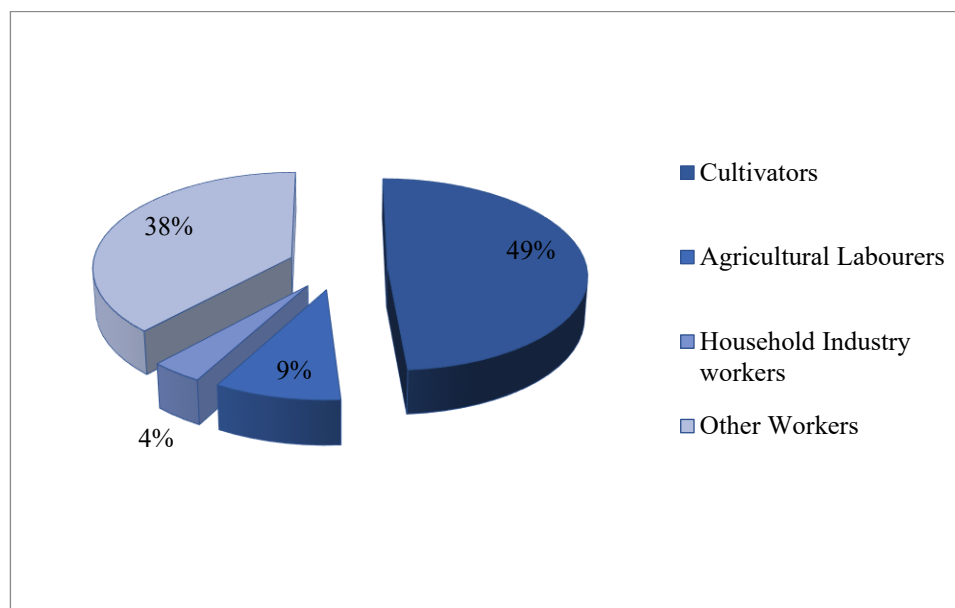


Figure 2.13: Economic activity of working population in Mokokchung District.

2.2.7. Road Networks

According to data from the Nagaland Public Works Department (PWD) for the fiscal year 2022-2023, Mokokchung district has an extensive road network (Figure 2.14) covering approximately 953.28 kilometers. This network plays an important role in ensuring transportation, economic activity, and connectivity both within the district and with neighboring regions. National Highways form an important part of this infrastructure, covering about 238.50 kilometers. These include: NH-2, which connects Mokokchung with Kohima and Imphal; NH-202 which connects Mokokchung with Tuensang and other parts of eastern Nagaland; NH-702D, which provides an important route to Assam, particularly Jorhat; NH-702A, which enhances intra-district connectivity through Zunheboto and Phek, improving regional accessibility. For internal and rural connectivity, the district has approximately 193.60 kilometers of State Highways, 34.80 kilometers of Major District Roads (MDR), and 386.75 kilometers of other district roads. These roads connect the district headquarters with sub-divisions and surrounding rural areas, supporting administrative and economic functions. Additionally, village roads extend over 338.13 kilometers, providing access to remote settlements and facilitating local movement, particularly for agricultural and livelihood activities. Despite having a relatively well-developed

road network, Mokokchung faces significant infrastructural challenges. The district's rugged terrain and heavy monsoonal rainfall often lead to road damage, erosion, and frequent landslides. Poor maintenance in certain stretches further affects transportation efficiency and connectivity, especially in remote areas.

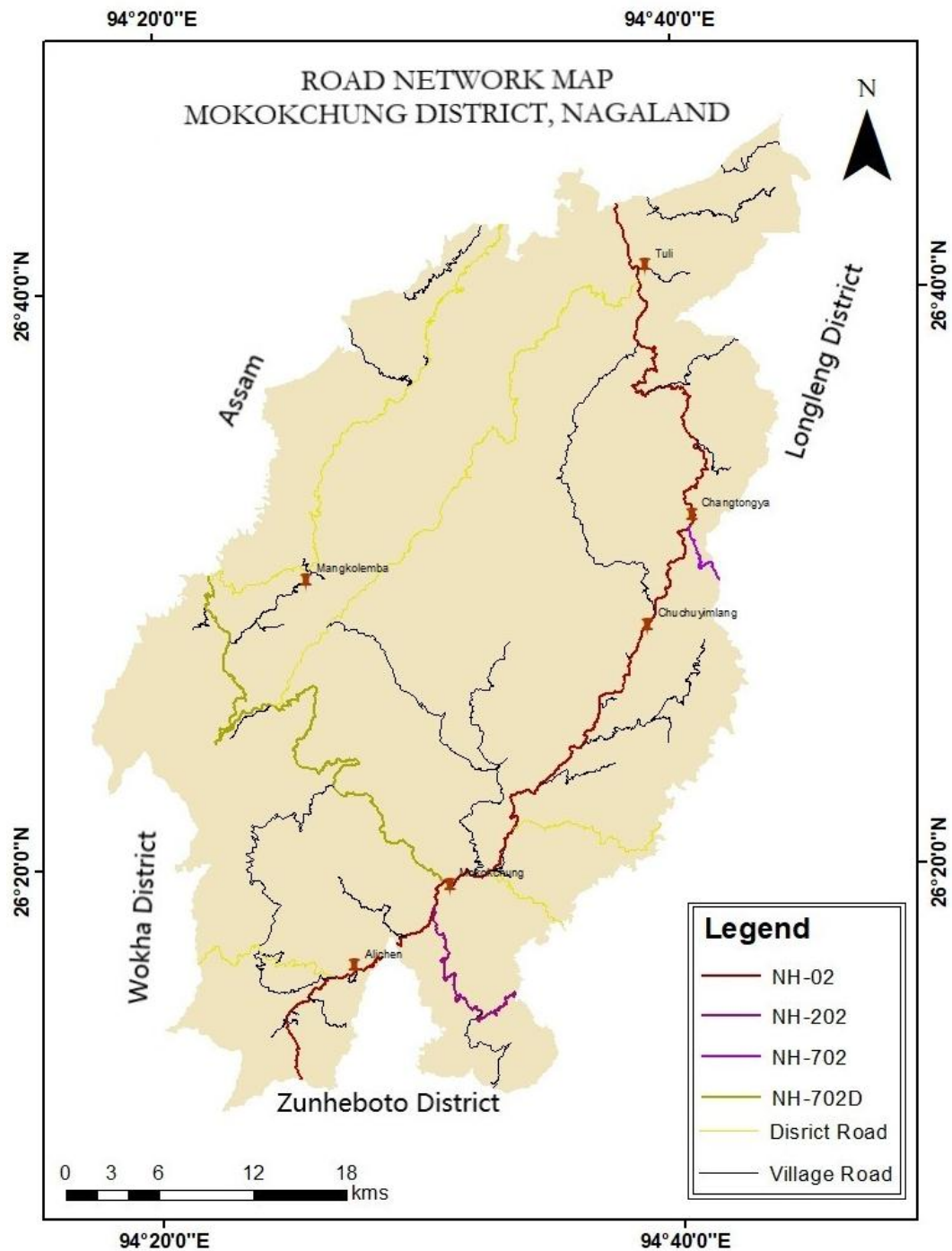


Figure 2.14: Transport Network Map of Mokokchung District.

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TERRAIN AND MORPHOMETRIC ANALYSIS

Terrain refers to the physical features of the earth's surface, including elevation, slope, and aspect. Morphometric analysis is a quantitative method used to assess these features, primarily through topographic maps or Digital Elevation Models (DEMs). This approach enables researchers to study the shape and structure of landforms using measurable parameters, to understand landscape evolution, drainage patterns, and surface processes (Pike et al., 2009; Strahler, 1957; Horton, 1945). The integration of GIS and Remote Sensing technologies has enhanced the accuracy and efficiency of terrain and morphometric analysis, allowing for large-scale terrain evaluations that inform environmental management, hazard assessment, and land-use planning (Jenson and Dominique, 1998; Moore et al., 1991). Analysis of the terrain and morphometric attributes of the study area helps interpret its geomorphic processes, landscape evolution, and environmental implications and is crucial as they directly influence the occurrence of geomorphological hazards. Key metrics such as drainage density, slope gradient, relief ratio facilitate watershed classification, erosion potential assessment, and inference of tectonic activity (Schumm, 1956; Miller, 1953). By analyzing these parameters, it becomes possible to understand the physical controls of hazard occurrence and to establish correlations with the spatial distribution of hazards, which will be highlighted in the later findings.

3.1. Digital Elevation Model: Digital Elevation Model (DEM) serves as a fundamental dataset in geospatial science, offering a precise, quantitative representation of the earth's surfaces in a digital form. According to Burrough and Mc Donnell (1998), a DEM is integral to analyzing topographic variation and geomorphological features, allowing for the extraction of critical spatial information such as slope, aspect, watershed boundaries, and terrain ruggedness. In the context of Mokokchung district, which is characterized by complex hill terrain and dynamic relief features: the DEM plays a major role in environmental planning, disaster risk analysis and infrastructure development.

The elevation of Mokokchung ranges from approximately 108 meters to 1905 meters above mean sea level. Based on the altitudinal range, the DEM has been categorized: 108-364 meters, 365-623 meters, 624-853 meters, 854-1132 meters and 1133-1905 meters (Figure 2.2). These elevation bands correspond to distinct physiographic zones, from river valleys to piedmont plains in the lower elevations to steep slopes and ridge tops in the higher regions. The lower elevations, primarily in the north and northwestern part of the district, consist of broader valleys and relatively gentle slopes. These areas are more conducive to human settlement and agriculture due to better accessibility and lower risk of erosion or landslides. In contrast, the southern and southeastern parts of Mokokchung exhibit higher elevations with rugged and steep topography. These zones are predominantly covered by dense forest and are prone to geomorphological hazards, especially landslides.

3.2. Lineament Density: Lineaments are the linear configuration of geomorphological features that may be continuous or interrupted without any distinct evidence of displacement, such as topographic break and structures (Ayalew & Yamagichi, 2005; Getachew & Meten, 2021). These features often serve as key surface traces of deep seated geological frameworks and the tectonic movements that have shaped a region through time (Reis et al., 2020) as areas with high lineament densities and steep slopes are often more prone to earthquakes and associated ground failures (Nebeokike et al., 2020). The lineament density of Mokokchung district (Figure 3.1) shows clear spatial variation, reflecting differences in the distribution and intensity of structural features. The major lineament orientations follow NE-SW and NW-SE trends which align with the tectonic framework of the Naga Hills, which form part of the eastern extension of the Himalayan orogenic system. Areas with high lineament density are mainly concentrated in the northern, southern and central parts of the district as depicted in Figure 3.1. Such zones are often indicative of active faulting and ongoing structural deformation. In contrast, the western and northeastern parts of the district display relatively low lineament density, suggesting comparatively stable and less disturbed terrain. The pattern and alignment of lineaments have a noticeable influence on geomorphological processes and the occurrence of hazards. Because lineaments represent fractures or zones of weakness in the underlying bedrock, areas where they

are concentrated tend to experience greater slope instability. When rocks are fragmented along these structural planes, their internal strength is reduced, making slopes more sensitive to gravitational stress. This vulnerability becomes more pronounced during episodes of heavy or sustained rainfall, when water infiltration further weakens the material and increases the chances of mass movement. Lineaments also shape the drainage network of the district. Streams and rivers commonly follow these structural trends, carving out linear valleys and intensifying erosion along their paths. In places where lineament density is high, gully erosion and rapid valley deepening are more evident, which can undermine slope stability over time. Such areas often characterized by steep gradients and fractured rock are therefore more prone to landslides, surface erosion, and localized flash flooding. The interaction between structural weakness and slope steepness ultimately creates conditions that favor repeated gravity driven processes, leading to more frequent landslides, mass wasting, and flash flooding. Additionally, lineaments act as pathways for groundwater movement and surface runoff and therefore water infiltrates easily along fractures and fault zones, resulting in concentrated subsurface flow. During heavy rainfall, this process can further destabilize the slopes and trigger failures.

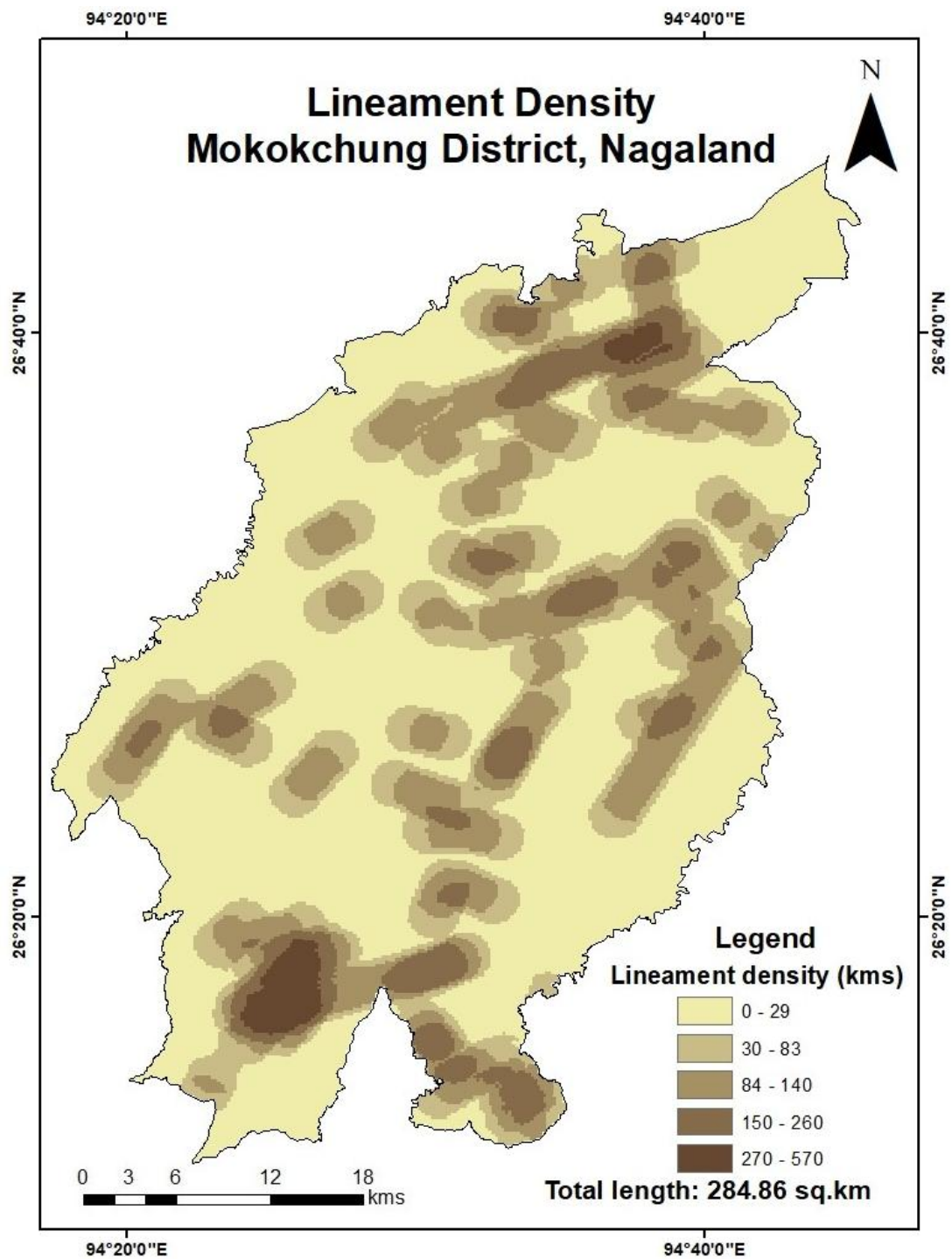


Figure 3.1: Lineament Density Map of Mokokchung District.

3.3. Soil:

The soils of Mokokchung district are generally deep, excessively drained, and composed of loamy, clayey, and skeletal materials developed over steep and undulating hill slopes. Their formation reflects the combined influence of rugged terrain, intense monsoonal rainfall, and complex geological conditions. Due to these interacting factors, soil characteristics vary greatly in texture, depth, and drainage, ranging from coarse and skeletal soils on steep slopes to finer textured deposits in gentler slopes and intermontane valleys as depicted in Figure 3.2. On steep hill slopes, soils are mostly shallow to moderately deep and often clayey or skeletal. These soils are highly porous and are excessively drained, usually found in rocky terrain with low moisture retaining capacity. As a result, such areas are highly prone to surface erosion, slope wash, and landslides, especially during heavy rainfall. In moderately sloping foothill and mid slope areas, soils are mostly deeper and loamy with moderate drainage and comparatively lower erosion risk. These areas can be more suitable for agriculture and settlement, as long as vegetation cover is maintained and slope stability is managed properly. On gentle slopes and hilltops, soils are usually more developed and finer in texture, with moderate drainage and reduced risk of erosion, making them suitable for forest cover and plantation based land use. Overall, the soil characteristics of Mokokchung closely reflect its geomorphological development under humid tropical conditions. The interaction between slope gradient, lithology, and seasonal rainfall creates spatial variation in soil stability and fertility. Consequently, soil erosion, gully formation, and landslides are common occurrences, especially in areas affected by deforestation and shifting (jhum) cultivation.

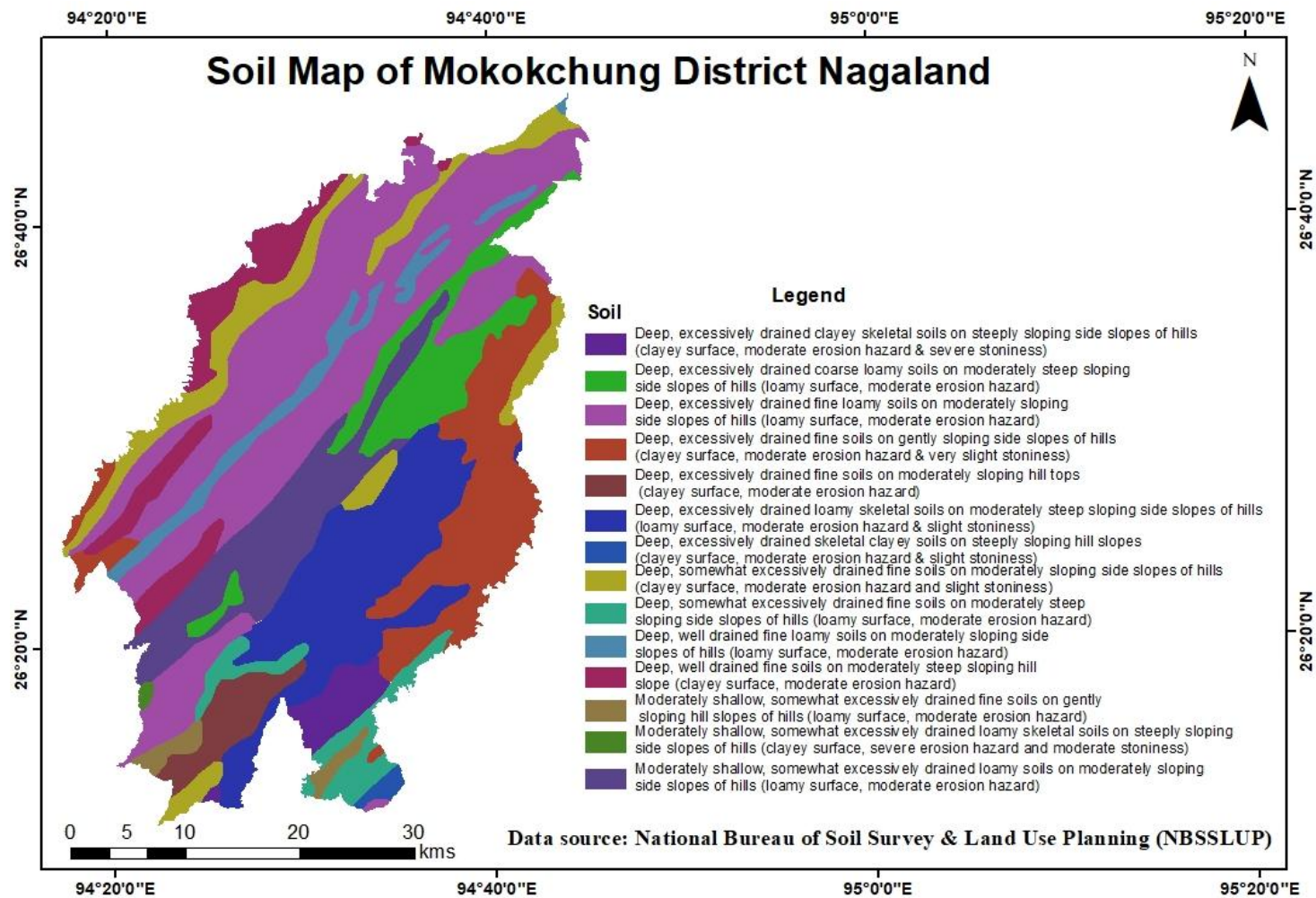


Figure 3.2: Soil Map of Mokokchung District (Source: NBSS & LUP)

3.4. Slope Gradient: Slope is an important geomorphological factor, which can be defined as the angle of inclination of the land surface relative to the horizontal plane. It plays a major role in the shaping of landforms, controlling of hydrological processes, influencing the intensity of erosion, and determining land use suitability. From a hydrological perspective, slope affects the velocity and volume of surface runoff, infiltration capacity, and soil erosion rates (Dai et al., 2002; Lingadevaru et al., 2015). Steeper slopes mostly result in rapid runoff and higher erosion, while gentle and nearly flat surfaces are more susceptible to water stagnation and water-logging (Krumbien et al., 1965). Such relationships can be observed in Mokokchung district, where intense seasonal rainfall and active tectonic influences increase the vulnerability of steep terrain to geomorphological hazards such as landslides and surface erosion. The slope gradient in Mokokchung ranges from less than 9° to about 70° , denoting a highly dissected and structurally controlled landscape. Based on different slope gradients, slopes in the district have been classified into five distinct categories (Figure 3.3).

Very gentle slopes (less than 9°): Very gentle slopes are mostly located in the western and northeastern parts of the district as depicted in Figure 3.3. These nearly level to gently undulating areas covers approximately 18% of the district's total land area and are characterized by lower elevations, river valleys, and depositional zones. Due to their relative stability and low erosion risk, these areas are highly suitable for agriculture, settlements, and infrastructure development.

Gentle slopes (10° - 17°): Gentle slopes cover approximately 22% of the district's total area and mostly occur as transitional zones between valley floors and moderately elevated hill regions as depicted In Figure 3.3. These slopes are mostly stable and can found in mid elevation areas which can support controlled land use and moderate cultivation, if appropriate soil and water conservation measures are implemented.

Moderate slopes (18° - 24°): Covering approximately 26% of the district's total area, moderate slopes are largely concentrated in the central and southeastern parts of Mokokchung as depicted in Figure 3.3. These areas show a notable increase in gradient and are more vulnerable to surface runoff, soil erosion, and shallow landslides.

Agricultural and infrastructural activities in these regions require careful terracing, erosion control measures, and sustainable land management practices.

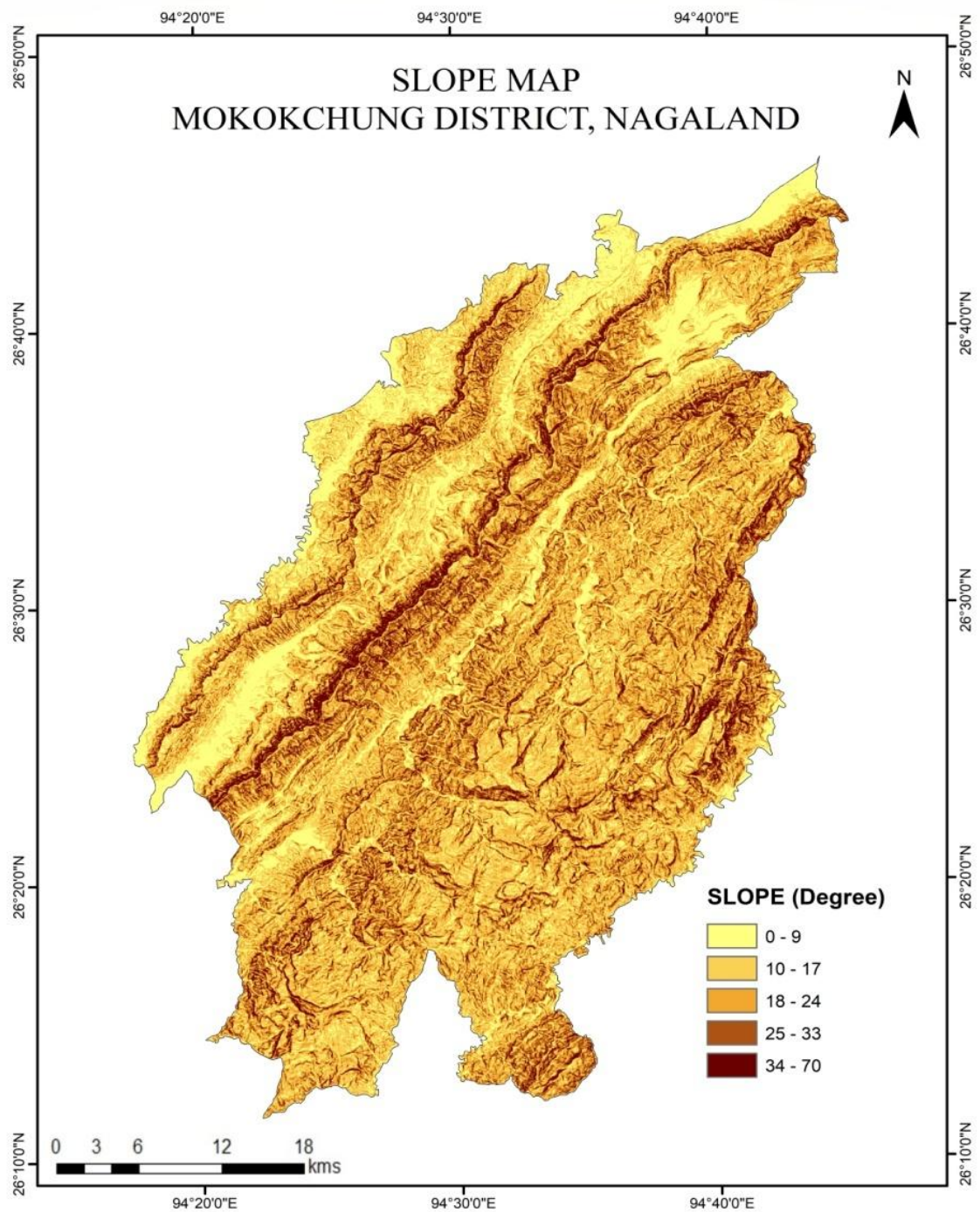


Figure 3.3: Spatial variability of slope gradient Map of Mokokchung District.

Steep slopes (25°-33°): Steep slopes cover approximately 20% of the district's total area and are mainly distributed along ridge lines and escarpments in the central and southern highlands as depicted in Figure 3.3. These areas face massive development challenges due to their inherent instability, high erosion potential, and increased susceptibility to landslides, especially during the monsoon season.

Very steep slopes (greater than 35°): It covers approximately 14% of the district's total area and is confined to the steepest hill faces, escarpments, and deeply incised valleys, especially in the central and southern highlands as depicted in Figure 3.3. These terrains are highly unstable and frequently experience landslides, rockfalls, and intense erosional activity, especially in areas where vegetation cover is sparse or absent.

3.5. Slope Aspect: It refers to the compass direction that slopes face points, measured clockwise in degrees from north (Dai et al., 2002; Kumar et al., 2008). It plays a major role in geomorphological and environmental processes by influencing the exposure of terrain to solar radiation, wind, rainfall, and wave action, which in turn affects soil moisture, weathering intensity, and rainfall patterns (Huang et al., 2017). Alamrew (2023) emphasizes that aspect governs the amount of solar radiation received by a slope, thereby impacting soil moisture and slope stability. Furthermore, aspect represents the downslope direction of the steepest rate of elevation change, which is fundamental for terrain analysis (Neuhäuser et al., 2012). Then, understanding slope aspect is essential for evaluating environmental processes and geohazard susceptibility in varied landscapes.

The aspect classification of Mokokchung district is divided into nine categories: north, northeast, east, southeast, south, southwest, west, northwest, and flat terrain. This classification denotes the variability in slope orientation across the district's rugged landscape. The aspect map as shown in Figure 3.4 indicates a highly heterogeneous distribution, reflecting the complex and dissected topography of Mokokchung. Eastern, southeastern, and northeastern aspects are the most dominant, particularly in the central and southern parts of the district.

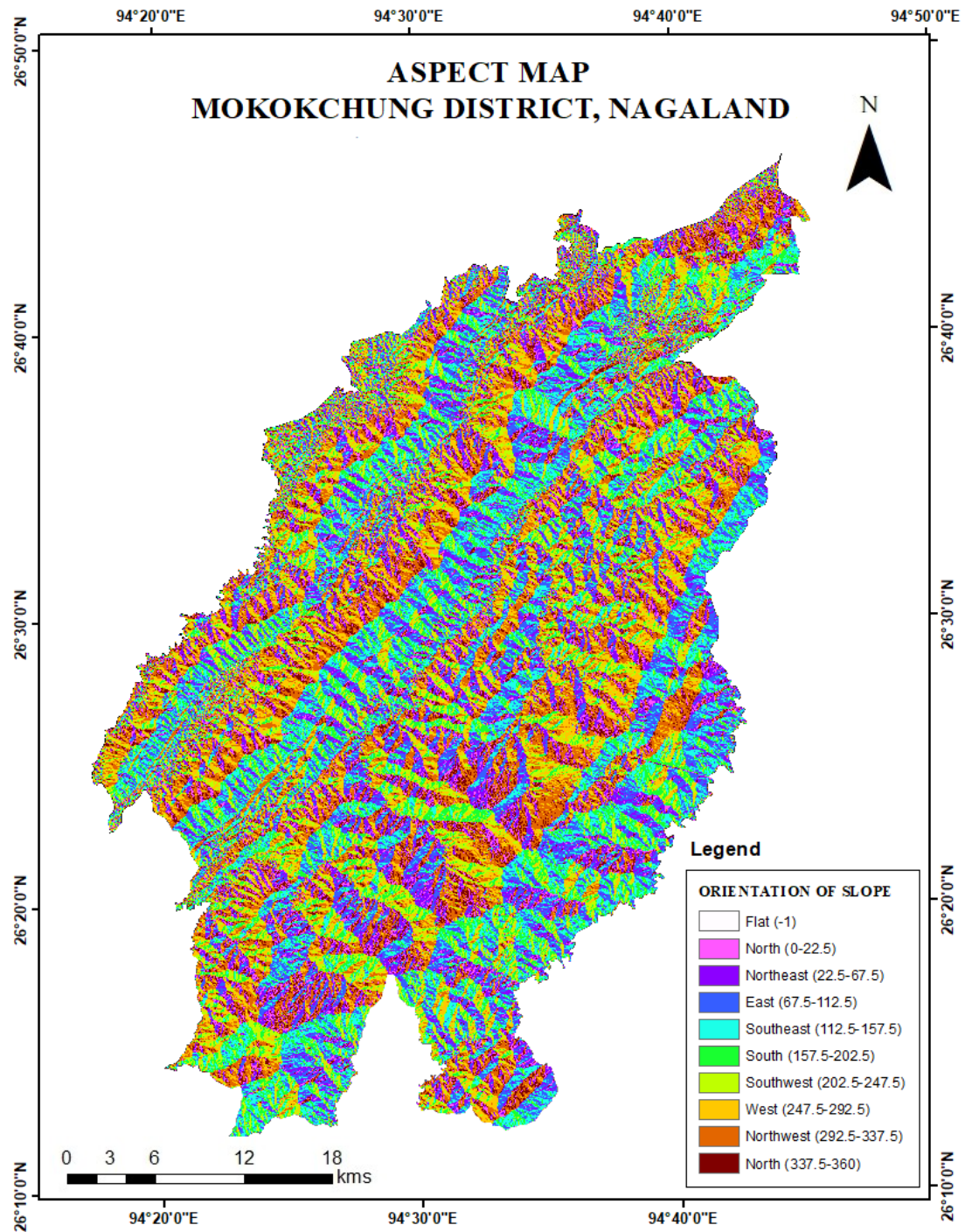


Figure 3.4: Slope Aspect Map of Mokokchung District.

These slopes generally receive abundant morning sunlight and because of the orographic influences in hilly terrain, these areas may also experience higher rainfall. Such conditions often promote active geomorphological processes and influence distinct vegetation patterns. North facing slopes are distributed throughout the district

and mostly remain cooler, as they receive less direct solar radiation. This reduced exposure allows them to retain higher soil moisture, supporting denser vegetation cover and lower evapotranspiration rates. In contrast, south facing slopes are less extensive but receive greater solar radiation, resulting in warmer and comparatively drier conditions. These slopes have mostly less vegetation and are more vulnerable to soil erosion and landslides, especially during intense rainfall events. West and northwest facing slopes further contribute to microclimatic variation by receiving strong afternoon sunlight, which influences local temperature regimes and moisture availability. Areas classified as flat terrain are less, suggesting the predominance of undulating to steep slopes and highlighting the overall rugged character of Mokokchung's landscape.

3.6. Contour Analysis: Contours inherently represent various terrain features, such as points along streamlines (Hutchinson and Gallant, 2000). Contour lines are essential for depicting the earth's topography. They are imaginary lines that connect points of equal elevation above a reference level, such as mean sea level or a designated benchmark. Contour data differ from other elevation data sources by suggesting a certain level of smoothness in the terrain they represent. By translating three dimensional terrain into a two dimensional format, contour lines enable the visualization of various landforms including hills, valleys, and slopes, and are particularly useful in regions of complex and undulating terrain such as Mokokchung district. The contour map of Mokokchung shown in Figure 3.5 represents the terrain using elevation based line features drawn at regular vertical intervals. It illustrates five distinct elevation ranges: 150 meters, 150.000001-450 meters, 450.000001-750 meter, 750.000001-1050 meters, and 1050.000001-1500 meters. The southern and central parts of the district are characterized by closely spaced contour lines, indicating steep gradients and elevated gradients. The northern and northeastern parts of the district, on the other hand, exhibit more widely spaced lines, suggesting gentler and relatively lower elevation zones. Contour lines forming closed loops indicate hills or elevated areas, with the innermost loop marking the summit, while the V-shaped contour patterns point upstream, indicating stream channels valleys.

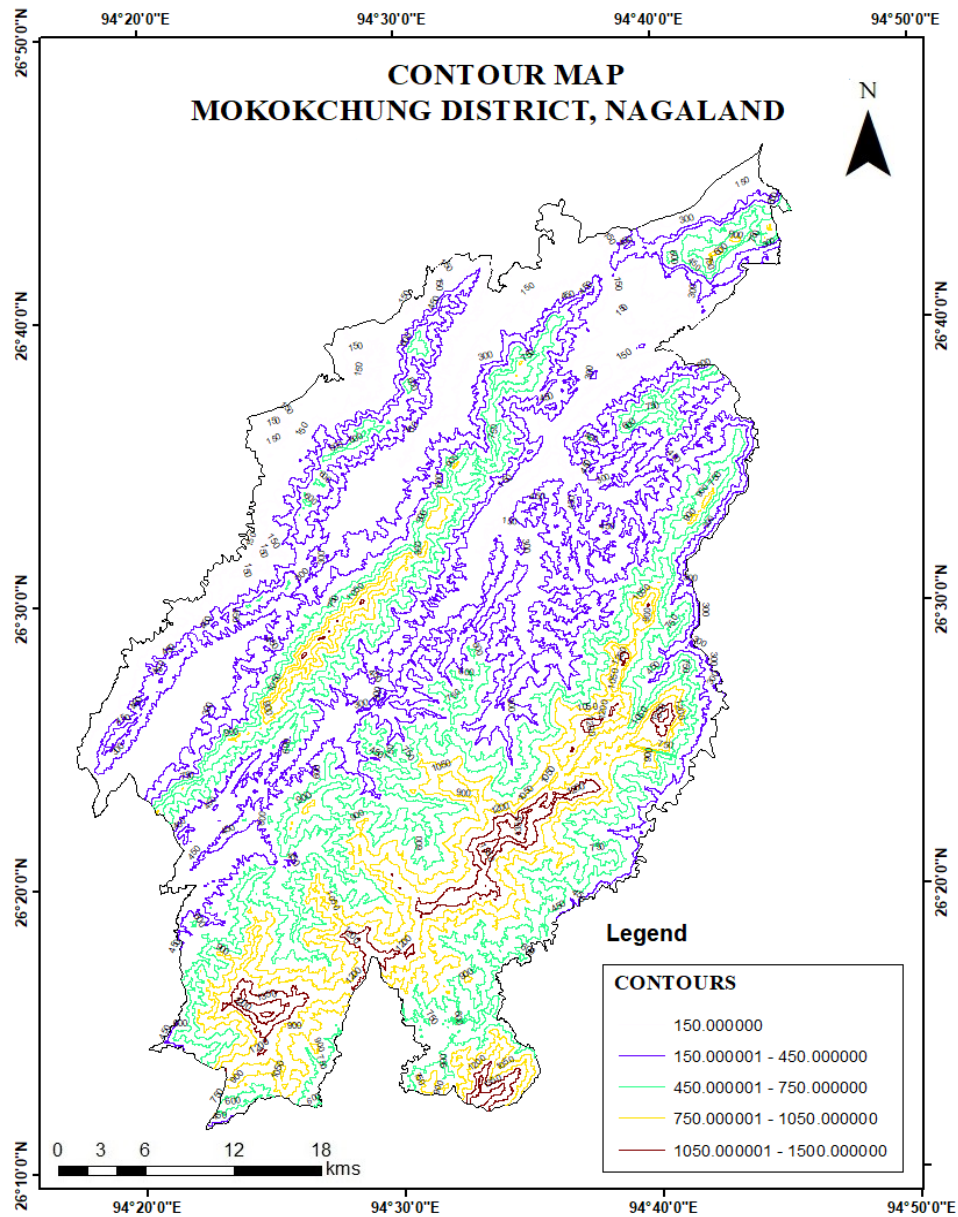


Figure 3.5: Contour Map of Mokokchung District.

3.7. Surface Roughness: Surface roughness is typically defined at human scale resolutions, ranging from centimeters to a few meters (Farr, 2015). It is an important metric in earth sciences that quantifies the complexity or variability of a land surface at a given spatial scale (Fan and Zhao, 2024). Surface roughness of the study area was evaluated using hillshade mapping. A hillshade map is a three dimensional visualization of the terrain that simulates the effects of sunlight on the landscape. By accounting the sun's position, it highlights the vertical and horizontal features of the

surface, offering an intensive geographical representation of terrain form. The hillshade map of Mokokchung shown in Figure 3.6 illustrates that the area is dominated by steep, rugged, and mountainous terrain. The central region shows moderate shading, indicating gentler slopes and lower elevation compared to other parts of the district. In contrast, the northern and southern regions exhibit elevated and highly dissected landscapes. This pattern of terrain variation is indicative of active geomorphic processes and aligns with previous physical assessments of the region.

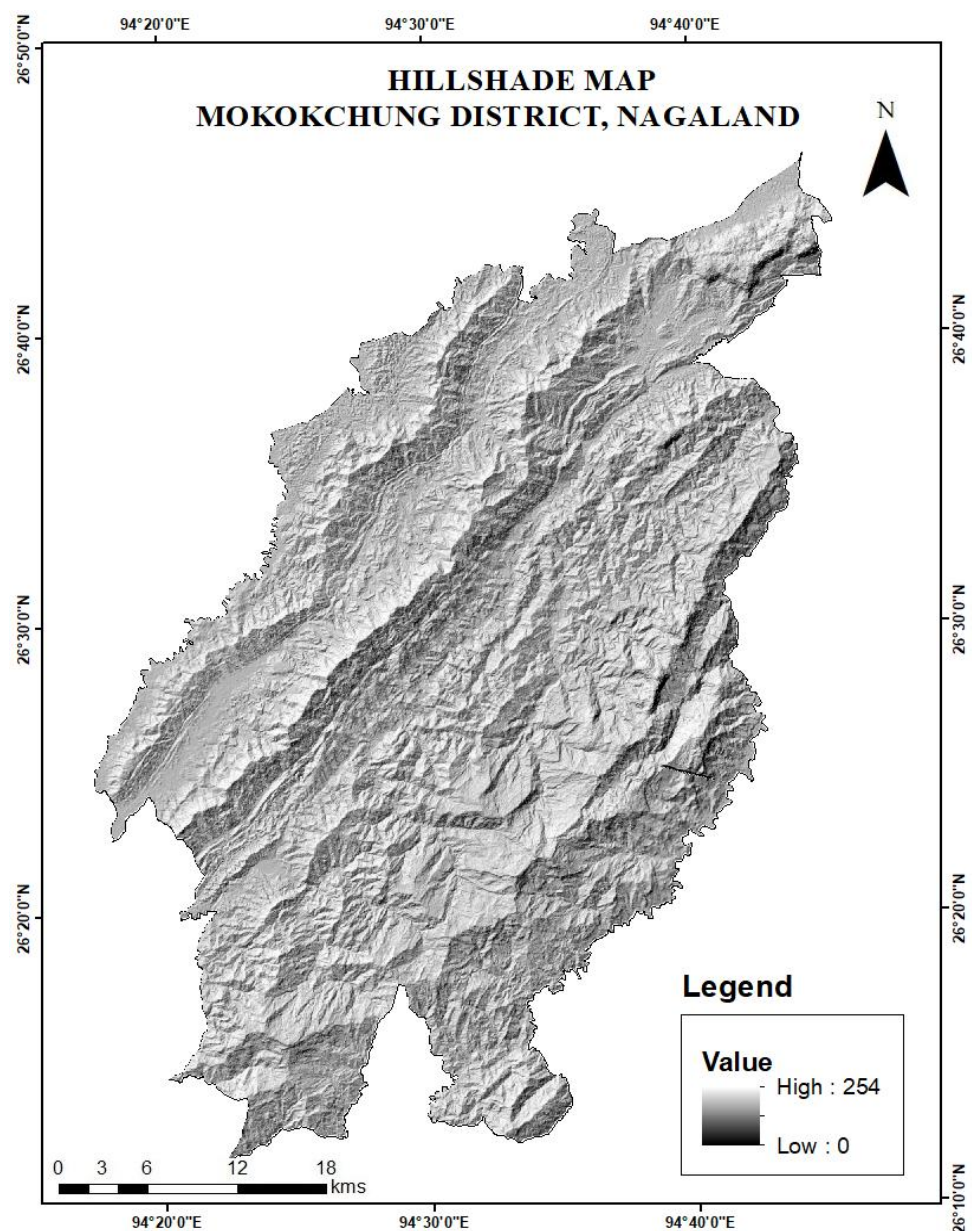


Figure 3.6: Hillshade Map of Mokokchung District.

3.8. Stream Order: Stream order refers to the hierarchical ranking of stream segments within a drainage network and serves as primary indicator of river system organization and its complexity. In this study, Strahler's (1957) stream ordering method has been applied in order to analyze the drainage network of Mokokchung district. According to Strahler's method, a first order stream is a headwater channel usually with no tributaries. When two first order streams join, they form a second order stream. Similarly, the confluence of two second order streams creates a third order stream, and this hierarchical process continues downstream. This system provides a structured approach for understanding drainage development and basin complexity. The drainage map of Mokokchung reveals a predominantly dendritic drainage pattern as depicted in Figure 3.7, denoting relatively homogeneous lithology and structural control over surface runoff. The network consists of streams up to the fifth order, reflecting a moderately developed drainage system. Approximately 250 first order streams are identified, mainly concentrated in peripheral regions and higher elevations. These headwater channels represent the most active zones of runoff generation and erosion. The convergence of first order streams forms about 100 second order streams, contributing to intermediate flow accumulation. Around 40 third order streams, characterized by limited tributaries, are mainly located in the central parts of the district. Nearly 15 fourth order streams act as major tributaries, flowing through major parts of the central landscape. The drainage system converges into 3 main fifth order streams, which involves major upstream networks and exhibit high discharge potential. The predominance of lower order streams denotes the highly dissected terrain and active erosional processes within the district. The hierarchical structure of the drainage network plays a crucial role in controlling runoff dynamics, transportation of sediments, and the occurrence of flash floods and slope instability.

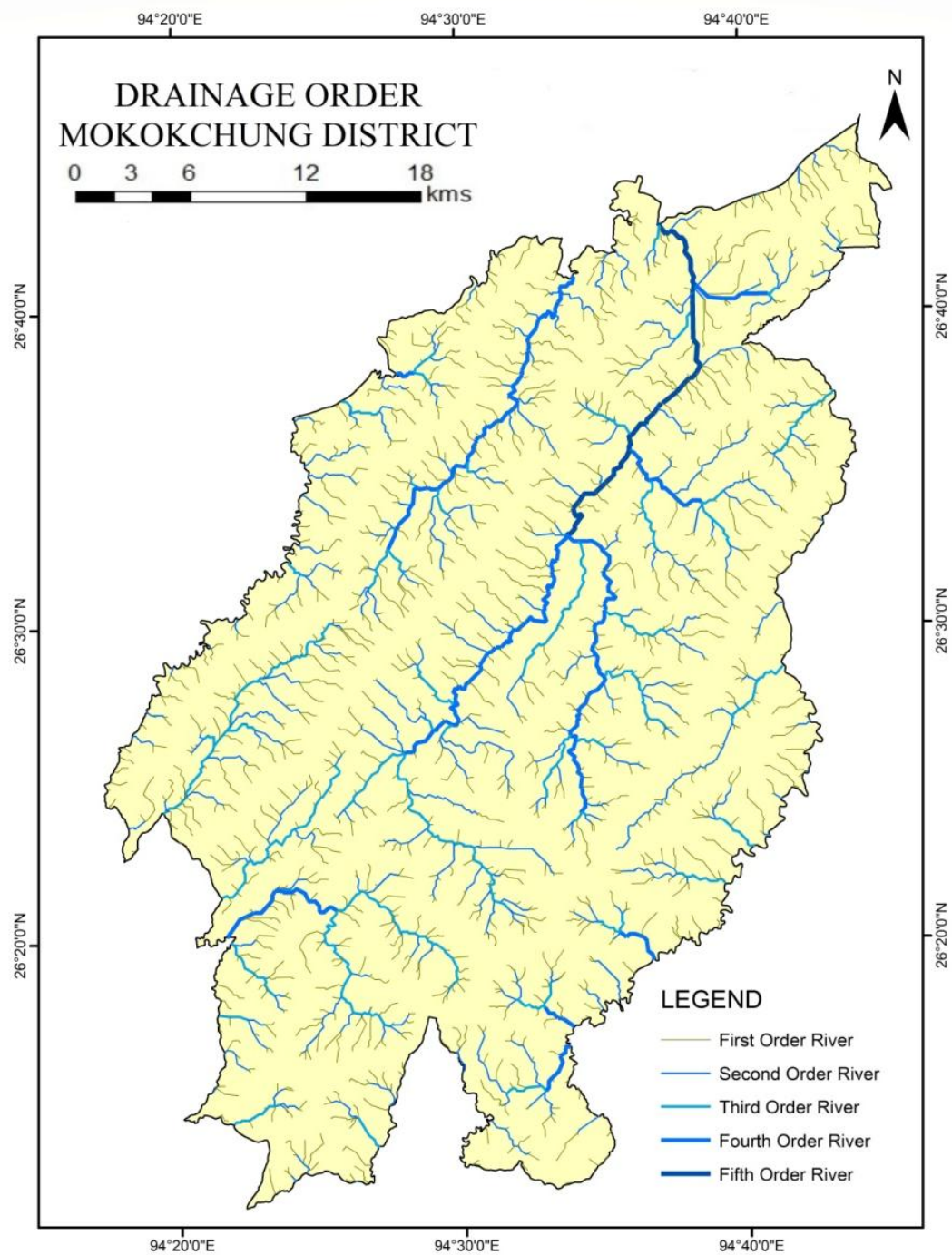


Figure 3.7: Drainage order Map of Mokokchung District.

3.9. Stream Length: The stream length of the study area has been calculated using Horton's law of Stream Length which asserts that the average length of stream segments increases with increasing stream order, generally following a geometric progression. This relationship reflects the systematic development and organization of a drainage network. In Mokokchung district, the average length of first order streams is approximately 1 km, while second order streams about 2 km. The third order streams extend to around 4 km, fourth order streams to nearly 7 km, and fifth order streams attain lengths of approximately 12 km. The progressive increase in stream length with stream order closely follows Horton's model and indicates a mature and well organized drainage system in the district.

3.10. Stream Frequency: Stream frequency refers to the number of stream segments per unit area of a drainage basin and is calculated by dividing the total number of streams of a given order by the basin area. For Mokokchung district, which covers an area of approximately 1615 km², stream frequency was calculated separately for each stream order. The analysis shows that first order streams are the most numerous, with a stream frequency of about 0.155 streams per km². Stream frequency declines steadily with increasing order, with second order streams recording 0.062 streams per km², third order streams 0.025 streams per km², fourth order streams 0.009 streams per km², and fifth order streams only 0.002 streams per km². This decreasing trend is characteristic of well developed drainage basins and reflects the hierarchical organization of the river network of Mokokchung.

3.11. Drainage Density: Drainage density is a significant geomorphological parameter which can be defined as the ratio of the total length of stream channels within a drainage basin to the total area of that basin (Horton, 1932). It interprets the degree of landscape dissection as well as the hydrological and erosional behavior of a region. Drainage density is influenced by factors such as lithology, climate, slope gradient, soil permeability, and vegetation cover. High drainage density generally depicts a well developed and efficient drainage network, where surface runoff is rapidly conveyed through channels rather than flowing as overland runoff. Consequently, areas with higher drainage density are more prone to rapid runoff and

flash flooding during intense rainfall events (Horton, 1932; Strahler, 1957). Such areas are often characterized by steep slopes, relatively impermeable soils, and sparse vegetation, conditions that encourage rapid surface flow. The concentration of fast moving water within channels increases stress on adjacent slopes, weakens soil structure, and raises the likelihood of slope failures and landslides (Montgomery & Dietrich, 1994). In addition, a dense network of streams can intensify erosion and undercut slopes, further destabilizing the terrain (Chen et al., 2006). In Mokokchung district, drainage density shows significant spatial variation, ranging from low (<1 km/km²) to very high (>5 km/km²) as depicted in Figure 3.8. The central and northeastern regions have higher drainage density values. These areas are highly dissected with steep slopes, relatively non porous rocks, and active erosional processes. As a result, they are mostly vulnerable to flash floods, rapid runoff, and landslides, especially during intense monsoonal rainfall. In contrast, the southern and outer western areas display lower drainage density (<1 km/km²), denoting relatively subdued topography and greater infiltration capacity. Although these areas face reduced immediate flood risk, they may still experience localized erosion if vegetation cover is disturbed. Overall, the predominance of moderate to high drainage density (1-5 km/km²) across much of Mokokchung highlights the geomorphic sensitivity of the study area. The dense drainage network gives rise to soil erosion, undercuts slopes, and increases susceptibility to hazards such as gully formation, landslides, flash floods, and bank erosion.

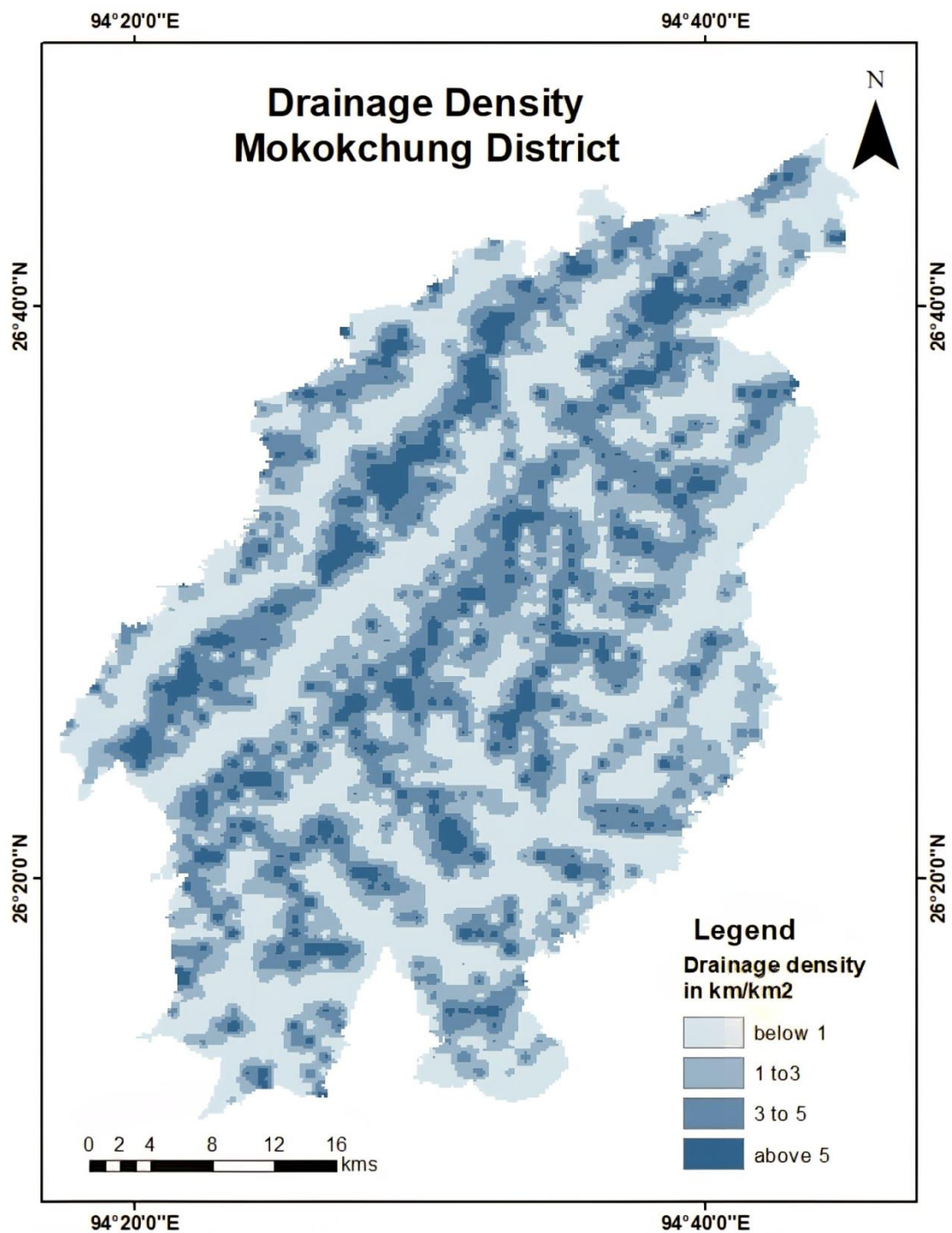


Figure 3.8: Drainage Density Map of Mokokchung District.

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**IDENTIFICATION, CLASSIFICATION AND MAPPING OF
GEOMORPHOLOGICAL HAZARDS**

Geomorphological hazards include a wide range of surface processes and landform dynamics resulting from the continuous interaction of geological, climatic, and anthropogenic factors. These hazards, whether gradual or sudden can exert significant effects on the physical terrain, human settlements, and ecological systems. Understanding their spatial patterns, causative factors and severity is essential for developing effective risk management and environmental planning strategies. The identification, classification and mapping of geomorphological hazards are fundamental aspects of geomorphological studies, enabling the visual identification of areas with varying susceptibility and determining targeted strategies for mitigation.

The geomorphological hazards in Mokokchung district are notably prominent due to the area's rugged topography, active tectonic setting, diverse lithological composition and substantial monsoonal rainfall. The district's terrain dissected by steep slopes and deeply incised valleys, is highly susceptible to both natural processes and human induced alterations such as deforestation, shifting cultivation, and expanding infrastructure. These factors collectively establish conditions to recurrent phenomena such as landslides, soil erosion, flash floods, and slope instability induced by earthquakes.

This chapter provides a comprehensive analysis of the major geomorphological hazards affecting Mokokchung district focusing on earthquakes, soil erosion, landslides, and flash floods. Each hazard represents a distinct yet interrelated geomorphic response to the region's environmental setting. By integrating systematic field surveys, remote sensing interpretations, and GIS based spatial analyses, it aims to delineate the distribution, intensity and underlying controls of these hazards.

4.1. Landslide Hazard in Mokokchung District

Landslides are one of the most destructive and frequently occurring geomorphological hazards worldwide, particularly in mountainous and hilly regions. These phenomena involve the downslope movement of soil, rock, and debris under the influence of gravity, and are often triggered by a combination of natural and anthropogenic factors (Cruden, 1991; Das, 2011; Motamedi, 2013). The mechanisms that lead to landslides are complex, requiring both predisposing internal conditions such as lithology, geological structure, slope morphometry, and hydrogeology and external triggers including rainfall, earthquakes, and human induced activities (Crozier, 1986; de Vallejo and Ferner, 2011). The process is fundamentally part of the earth's natural erosion system, constantly reshaping surface features over time (S, Arbanas and Z. Arbanas, 2015). Globally, the occurrence and impact of landslides have significantly increased over recent decades. According to the Emergency Events Database (EM-DAT), between 1900 and 2020, there were 680 records of landslide events worldwide, resulting in 63,376 fatalities and affecting over 14 million individuals. Landslides now account for approximately 5.2% of natural hazard events globally (CRED, 2018) and are responsible for annual damages estimated at 18 billion Euros (Zhu et. al., 2018). Studies have shown that the increasing impacts are closely related to factors such as population growth, expansion of human settlements into vulnerable areas, and unregulated land-use changes (Tegeje, 2017; Chalise et. al., 2019; Turner, 2018). Extreme weather patterns associated with climate change have further intensified landslide occurrences in recent years (Zou et. al., 2021).

Asia, home to many of the world's major mountain ranges has been the most affected. Between 1900 and 2020, the continent experienced 348 landslide events, causing approximately 21,653 deaths and affecting over 8.7 million people. In Asia, landslides are especially frequent in tectonically active regions with steep topography and heavy rainfall, such as South and South-east Asia (Kanungo et. al., 2006; Ghosh et. al., 2011). Rainfall induced slope failures, along with those triggered by seismic activity and anthropogenic alterations are a major concern across the continent (Agliardi et. al., 2012; Gupta et. al., 2021). India is among the most landslide prone

countries in Asia, with approximately 0.42 million km² or nearly 12% of its landmass classified as vulnerable to landslides (Geological Survey of India). The country's diverse physiography and climatic zones contribute to a wide range of landslide types and triggering mechanisms. The Himalayan region in particular, represents the most landslide prone areas in India due to its young, rugged topography, fragile geological formations, frequent seismic activity, and high mountainous belts, slope instability is further exacerbated by human interventions such as road construction, deforestation, urban expansion, and changes in land-use practices (Das et. al., 2011; Jaboyedoff et. al., 2018).

The northeastern state of Nagaland situated in the Eastern Himalayas, is particularly susceptible to landslides due to its fragile geology, steep terrain, and high rainfall. Within Nagaland, Mokokchung district is a notable example of recurring landslide events. Owing to its geographical location, Mokokchung district is afflicted by numerous landslides every year causing adverse effects on the natural environment and economy. Landslide is a major geomorphological hazard that keeps affecting the study area, especially during monsoons when heavy rainfall is experienced. It is further intensified by erratic and unhindered rapid anthropogenic activities. Mokokchung district of Nagaland is characterized by moderately weak topography, young mountainous terrain and receives abundant rainfall during the monsoon. Consequently, landslide geomorphological hazard is quite active and a recurrent phenomenon in Mokokchung.

Given the above mentioned scenario, recognizing and specifying the potential distribution of landslides through landslide susceptibility mapping (LSM) is thereby crucial, as it weighs the probability of landslide occurrence and the resulting information plays a vital role for policy makers in managing and mitigating losses (Corominas et al. 2014, Wang et al., 2021). Landslide hazard mapping operates on the premise that future landslides are likely to occur in areas with geo-environmental conditions similar to those of past and present landslide sites (Varnes, 1984; van Beek, 2002; Kanungo et al., 2012).

The assessment of landslide hazard pertains to the estimation of the probability of such occurrences taking place within a specified area, achieved through the analysis of the cumulative effects of a variety of geo-environmental factors (Tian et al., 2020; Zhang Y. et al., 2020, Zhou et al., 2021). A comprehensive assessment of landslide inventory and their causative variables will enable the generation of a landslide susceptibility map, potentially mitigating the impacts of landslides on property and human life (Brabb 1993). The landslide susceptibility map can be generated by analyzing the spatial relationship between landslides and their contributing factors. Several research has produced various approaches for evaluating landslide susceptibility, indicating that damage from natural processes has escalated in recent decades (Althuwaynee and Pradhan 2016; Hong et al. 2015; Shahabi et al. 2015, Jazouli. 2019). These approaches can be categorized into two primary types: qualitative techniques and quantitative techniques, each employing a set of indicators. The qualitative techniques require the researcher's extensive field investigation/knowledge and involve distribution analysis, or inventory and geomorphic analysis (Corominas et al. 2014; Raghuvarshi et al. 2014; Shano et al. 2020). Expert Scoring and Analytical Hierarchy process (AHP) are some Qualitative techniques. Quantitative techniques on the other hand, utilize mathematical and statistical models to derive numerical estimates (probabilities) on the occurrence of landslide events in any hazard zone (Guzetti et al., 2000). The frequency ratio approach and the certainty factor method are of the quantitative approaches utilized for landslide susceptibility mapping.

The Analytical Hierarchy Process (AHP) has been widely recognized as a powerful tool in landslide hazard assessment, enhancing the accuracy of susceptibility mapping by systematically assigning weights to various influencing factors. Numerous studies have successfully applied this model in different regions, demonstrating its effectiveness in identifying high risk areas and supporting disaster management strategies. For instance, Mandal and Mandal (2018) applied AHP in the Lish river basin of Eastern Darjeeling Himalaya, to assess landslide susceptibility using a combination of slope angle, slope aspect, slope curvature, altitude, relative relief, geomorphology, geology, distance to lineaments, lineament density, soil, land use & land cover, NDVI, drainage density, distance to drainage, stream power index,

topographic wetness index, and rainfall factors. The model's accuracy was validated using landslide susceptibility and cumulative percentage of landslide occurrence, reinforcing its reliability in hazard prediction. Anbalagan et al. (2015) conducted a comprehensive investigation to identify and map landslide hazard zones in the Lachung Valley of Sikkim, utilizing geospatial analysis and field data to better understand the spatial distribution and risk levels of landslides in the area. Similarly, Jazouli et al. (2019) conducted a landslide susceptibility study in the Oum Er Rbia high basin of Morocco, utilizing a GIS based AHP model. By incorporating critical terrain parameters such as land cover, lithology, distance to road, distance to fault, distance to drainage network, elevation, aspect and slope gradients, the study effectively highlighted high risk zones. The weighted overlay analysis significantly improved the precision of hazard zonation, aligning closely with real world landslide occurrences. This study demonstrated how AHP can be instrumental in early warning systems and sustainable land use planning. In view of these, the present study implements the Analytical Hierarchy Process (AHP) to evaluate and assess the causative factors and sub factors in order to produce a landslide susceptibility map for Mokokchung district in Nagaland.

4.1.1. Methodology

4.1.1.1. Preparation of GIS spatial database: The present study was conducted to assess landslide susceptibility and risk in Mokokchung district through an integrated analysis of geophysical, ecological, and hydro-meteorological parameters using both remote sensing and field based data. Various geophysical aspects including geology, geomorphic landforms and drainage systems, were studied using Survey of India (SOI) topographic maps (83J/6, 83J/7, 83J/8, 83J/9, 83J/10, and 83J/11) at a scale of 1:50,000, along with high resolution Google Earth imagery at different scales. Topographic parameters such as relief patterns, slope gradients, slope aspects, flow accumulation, and drainage morphometry were derived from a 30 meter resolution Digital Elevation Model (DEM) obtained from NASA's SRTM satellite data. Landslide inventory mapping, land use/land cover (LULC) classification, and extraction of photo lineament features were carried out using digital image

processing techniques such as supervised classification, band ratio methods, and the Normalized Difference Vegetation Index (NDVI). USGS-Landsat satellite imagery with a spatial resolution of 30 meters was utilized to analyze ecological factors, including vegetation cover and land use patterns, relevant to slope stability assessments. Rainfall data spanning over three decades (1991-2022) was collected from the CHRS Data Portal and in addition to records from ground based meteorological stations managed by the Indian Meteorological Department (IMD) within and around Mokokchung district. This rainfall data was used to calculate average monthly and annual precipitation, which was then converted into raster layers using the inverse distance weighting (IDW) interpolation method to analyze spatial rainfall variability across the district.

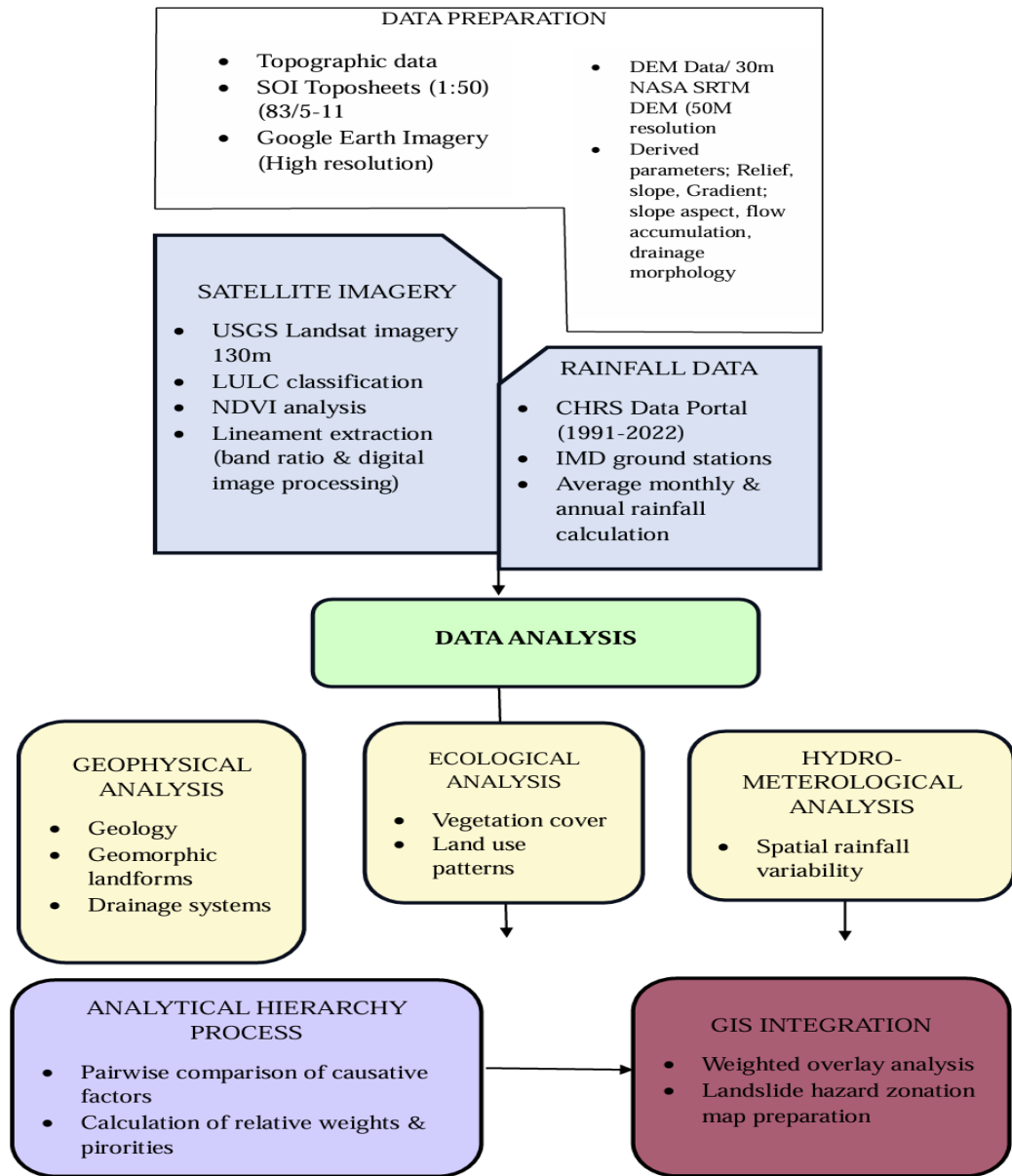


Figure 4.1: Methodology for landslide hazard zonation in Mokokchung District.

4.1.1.2. AHP based integration of landslide factors in GIS for hazard zonation:

To assess the susceptibility of landslide in Mokokchung district, the Analytical Hierarchy Process (AHP) developed by Saaty (1980) was used in order to determine the relative importance of different causative factors. AHP is a widely used multi-criteria decision making method that helps assign weights to various factors through systematic pair-wise comparisons based on informed judgment (Saaty, 2008).

In this study, all relevant landslide causing factors were first prepared as thematic layers in raster format with a spatial resolution of $30\text{ m} \times 30\text{ m}$. Each layer was further divided into sub factors depending on its characteristics and its possible influence on landslide occurrences. In order to determine how important each factor was in triggering landslides, a pair-wise comparison matrix was created. In this matrix, every factor was compared with every other factor to evaluate its relative contribution to slope instability. These comparisons were carried out using Saaty's nine point scale, where a value of 1 indicates equal importance between two factors, and a value of 9 indicates extreme importance of one factor over the other. From this matrix, normalized weights were then calculated using the principal eigenvector method. To ensure that the comparisons were logically consistent and reliable, the Consistency Ratio (CR) was evaluated. A CR value below 0.1 was considered acceptable, indicating that the judgments made during comparison were consistent. The final weights obtained for each factor were then assigned to their respective thematic layers. These weighted layers were integrated in a GIS environment using a weighted linear combination overlay technique. The resulting landslide hazard zonation map classifies Mokokchung district into different susceptibility zones ranging from very low to very high. This map serves as an important tool for planning, hazard mitigation, and informed decision-making, helping authorities better manage and reduce landslide risk in the district.

4.1.2. Landslide influencing Parameters: A set of key parameters influencing landslide occurrence was identified and incorporated into the analysis. These include slope gradient, rainfall, lineament density, geology, drainage density, geomorphology, land use pattern, elevation, NDVI and slope aspect. Continuous factors were further classified into different sub factors in order to represent their spatial variability across the study area. A detailed description of each parameter has been discussed as under:

4.1.2.1. Slope: Slope is one of the most important factors controlling the occurrence of landslides, as both the angle and orientation of a slope significantly influence the stability of the terrain and the likelihood of failure (Cruden, 1991). Steeper slopes are generally more prone to landslides due to increased gravitational stress and reduced

resistance whereas, areas with moderate to gentle slopes tend to exhibit relatively lower landslide susceptibility. Likewise, a higher slope contributes to an increased risk of landslide as a result of slope failure due to the instability of the underlying surface (Tofelde et al. 2017). Derived from DEM 30 m in ArcGIS, slope ranges from 0-70° in Mokokchung District (Figure 3.3). The slope angle map is re-classified into 5 classes: very gentle slope (0-9°), gentle slope (10°-17°), moderately steep slope (18°-24°), steep slope (25°-33°) and very steep slope (34°-70°). The slope gradient variability in Mokokchung district indicates that a substantial proportion of the total area is dominated by steep slopes ranging from 18°-33°. Weightage value of slope gradient calculated through Analytical Hierarchy Process (AHP) model stands at 0.398, while the scale for pair-wise matrix has been assigned in accordance with the steepness of the slope i.e. 1, 3, 5, 6 and 7 for very gentle, gentle, moderate, steep and very high slopes respectively.

4.1.2.2. Rainfall: Rainfall is a major triggering factor for landslide occurrence in the study area, as it is in most areas across the world. When rainfall is intense or prolonged, it can infiltrate the soil and cause water table to rise, increasing the pore water pressure and reducing the soil's shear strength (Iverson, 2000). Landslides typically occur if consistent rainfall reaches a specific threshold (Guzetti et al., 2008). Average rainfall of Mokokchung for a period of 20 years from 2001-2022 has been analyzed with rainfall data acquired from CRIS, CRU and IMD. Rainfall in the study area varies from year to year. Rainfall variability indicates that the average annual rainfall of Mokokchung District ranges from 954-999 mm (Figure 4.2). Majorities (around 70%) of annual rainfall is concentrated between the months of June and September during the peak rainy season and it is when most of landslides take place. The weight value of rainfall in the Analytical Hierarchy Process (AHP) is 0.254. The scale for pair-wise matrix of average annual rainfall has been assigned as follows: 2 for rainfall between 954-999 mm, 3 for rainfall between 999-1023 mm, 5 for rainfall between 1023-1043 mm, 7 for rainfall between 1043-1061 mm, and 9 for rainfall between 1061-1094 mm.

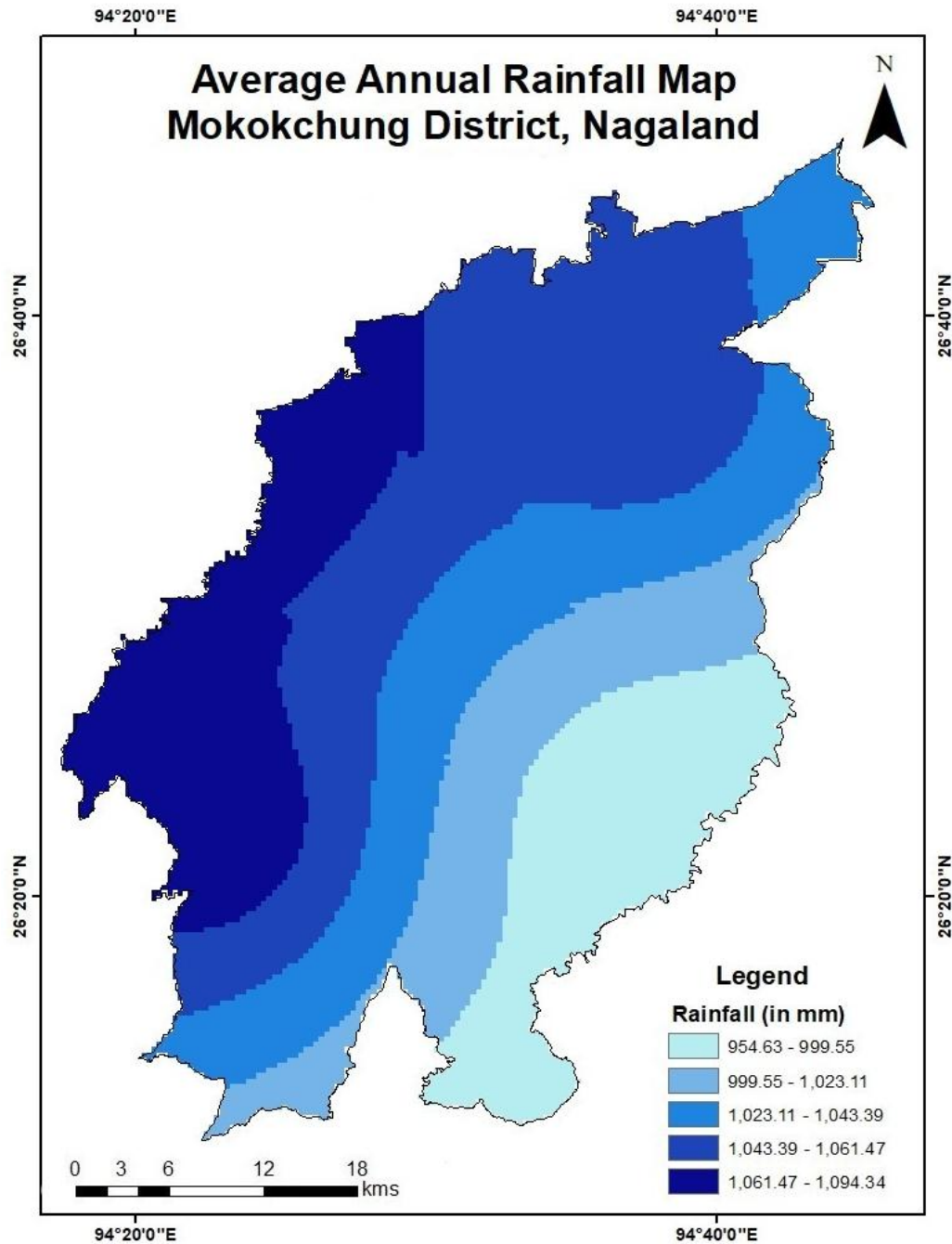


Figure 4.2: Average annual rainfall map of Mokokchung District.

4.1.2.3. Lineament Density: Lineaments are linear geomorphological features that may be continuous or discontinuous and often represent structural weaknesses such as fractures, faults, or lithological boundaries, without any distinct signs of displacement (Ayalew & Yamagichi, 2005; Getachew & Meten, 2021). A high density of lineaments indicates an increased presence of structural breaks in the bedrock, which weakens

slope materials and enhances water infiltration, thereby increasing landslide susceptibility (Sarkar & Kanungo, 2004). In the study area, proximity to lineaments plays a significant role in controlling landslide occurrence along slopes. The lineament density map of the study area was classified into five distinct density classes (Figure 3.1). Based on the AHP analysis, a weight value of 0.159 was assigned to lineament density, reflecting its relative importance among the selected causative factors. The pair-wise comparison scale for lineament density was assigned as follows: 3 for densities ranging from 0-29, 5 for 30-83, 6 for 84-140, 8 for 150-260, and 9 for the highest density range of 270-570. Increasing scale values correspond to greater structural complexity and higher landslide susceptibility.

4.1.2.4. Geology: Geology plays a crucial role in influencing the slope stability of Mokokchung district as the region is characterized by young, fragile, fractured and decomposed rocks. The study area is comprised of four main lithological units namely the Barail group, Disang group, Surma group and Tipam group (Figure 2.6). Disang Group is a group of monotonous sequence of grey, khaki grey to black splintery shales with silty interbands, lensoidal sandstones, (6-8m thick) and rhythmites (Geological Survey of India, 2011). Barail group comprises of very thick sequence of hard, ferruginous, thickly bedded sandstone with minor shale and siltstone, shale carbonaceous shale siltstones and sandstones with a number of coal seams, well bedded, laminated sandstone occasionally with alternating siltstones (Geological Survey of India, 2011). Surma group is characterized by basal conglomerate with wide variations from a few cm to 13 meters. It essentially consists of an alternation of shale, siltstone and sandstone, with intervening pebble beds and conglomerates (Geological Survey of India, 2011). Tipam group comprises of thickly bedded bluish grey to light grey ferruginous sandstones with thin interbands of siltstones and shales, which become light brown on weathering. Coarse grained sandstones with distinctive bedding patterns are the main features of this rock (Geological Survey of India, 2011). The weight value of geology for the study area, as determined by the Analytical Hierarchy Process (AHP) is 0.093. The pair-wise matrix scale for geology of Tipam group, Surma group, Disang group and Barail group has been assigned 1, 2, 3 and 4 accordingly.

4.1.2.5. Drainage Density: Drainage density defined as the total length of streams per unit area of a basin, is a critical morphometric parameter influencing geomorphological processes, including the occurrence of landslides. High drainage density generally indicates a highly dissected landscape with steep slopes, less infiltration, and rapid surface runoff, all of which can increase the susceptibility to landslides and related geomorphological hazards. Drainage density of Mokokchung as shown in Figure 3.8 exhibits considerable spatial variability, ranging from areas with low drainage density ($<1\text{km/km}^2$) to zones of very high drainage density ($>5\text{km/km}^2$). The Analytical Hierarchy Process (AHP) weight value of drainage density for Mokokchung district stands at 0.072. The pair-wise matrix scale for drainage density has been assigned as: 2 for drainage density below 1, 3 for density 1-3, 5 for density between 3-5, and 6 for density above 5.

4.1.2.6. Geomorphology: Using GIS technology, geomorphological research was carried out and confirmed by comprehensive field study of the area to assess the impact of diverse endogenic and exogenic processes on landslide occurrences. The study area features extensively dissected hills and valleys with height ranging from 400 m to 2000 m above mean sea level. It exhibits a rugged topography with glens, gorges, narrow valleys and linear ridges. Geomorphological units that make up the study area are: younger alluvial plains, water bodies, pediment pediplain complex, moderately dissected structural hills and valleys, low dissected structural hills and valleys and highly dissected structural hills and valleys (Figure 2.4). The weight value of geomorphology in the Analytical Hierarchy Process (AHP) is 0.037. The scale for pair-wise matrix of geomorphological units has been assigned as follows: 1 for Alluvial Plains, 2 for Pediment Pediplain Complex, 4 for lowly dissected structural Hills and Valleys, 7 for moderately dissected structural Hills and Valleys and 9 for highly dissected structural Hills and Valleys.

4.1.2.7. Land-Use pattern: Land use change and pattern contributes significantly to the initiation and reactivation of landslides (Guillard and Zezere, 2012; Galve et al., 2015; Meneses et al., 2019), while also regulating the spatial distribution of landslide consequences (Promper et al., 2014). Varied land cover types exhibit distinct

vegetation characteristics, as do their influence on soil conservation and surface water, both of which are linked to slope surface stability and enforcing to a certain degree on the occurrences of landslide (Penghui et al., 2021). Likewise, areas with dense vegetation are less prone to landslides while barren lands and built-up areas are more prone to landslides. Therefore, land use pattern is an important conditioning factor of landslide. Many studies also suggest that land use land cover changes might also increase landslide susceptibility (Chen and Huang, 2013). By creating polygons, land cover data were extracted from Google Earth Image 2023 and Arc GIS 10.3 software was used to produce the results which have been shown in Figure 4.3. The results show that 89% of the region's total area is covered by dense and open forest, followed by built up areas (5%), agricultural land (3%), water bodies (2%) and barren land (1%). Weightage value of land use pattern calculated through Analytical Hierarchy Process (AHP) model stands at 0.058, while the scale for pair-wise matrix for open forest, open forest, agricultural land, built-up area and barren land has been assigned 1, 2, 4, 7 and 8 accordingly.

4.1.2.8. Relief: Elevation is a key aspect in occurrence of landslides, as higher elevations increase landslides risk due to steeper slopes, intensified weathering and greater gravitational stress, all of which contribute the slope instability and the likelihood of landslides. The elevation of Mokokchung ranges from approximately 108 meters to 1905 meters mean sea level (Figure 2.2). The relief factor for landslide was assigned a weight value of 0.039. Based on the altitudinal range, pair-wise comparison matrix for the five stratified classes are: 2 for elevations ranging between 108-364, 4 for elevations ranging between 365-623, 6 for elevations ranging between 624-853, 7 for elevations between 854-1132, and 8 for elevations ranging between 1132-1905.

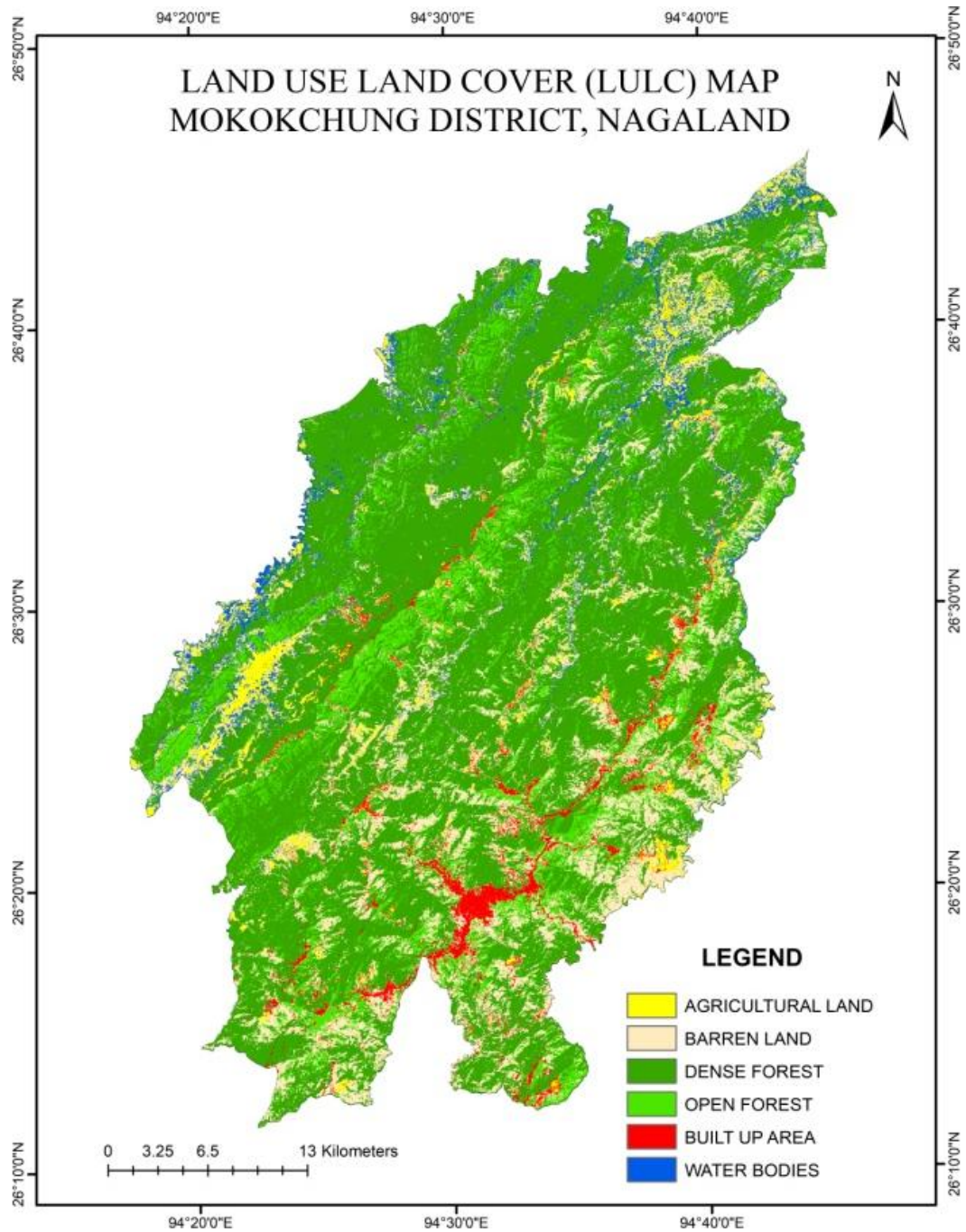


Figure 4.3: Land Use land Cover Map of Mokokchung District.

4.1.2.9. NDVI: The Normalized Difference Vegetation Index (NDVI) reflects vegetation health and groundwater availability, both of which can influence the initiation and progression of landslides (Lee, 2004). Low NDVI values suggest sparse or degraded vegetation, increasing slope stability, while high NDVI values indicate healthy vegetation that stabilizes slope, and reduces landslide risk. NDVI for the study

area has been categorized into five distinct classes (Figure 4.4): barren or sparse vegetation (-0.06-0.18), sparse vegetation (0.18-0.25), moderately sparse vegetation (0.25-0.29), moderate vegetation (0.29-0.34), and dense vegetation (0.34-0.42). Areas with low NDVI values indicating sparse or no vegetation were given the highest priority i.e., 6 due to their high landslide vulnerability, followed by 5 for sparse vegetation, 3 for moderately sparse vegetation, 2 for moderate vegetation and 1 for dense vegetation. The overall value of NDVI for Mokokchung as determined by the Analytical hierarchy Process (AHP) is 0.022.

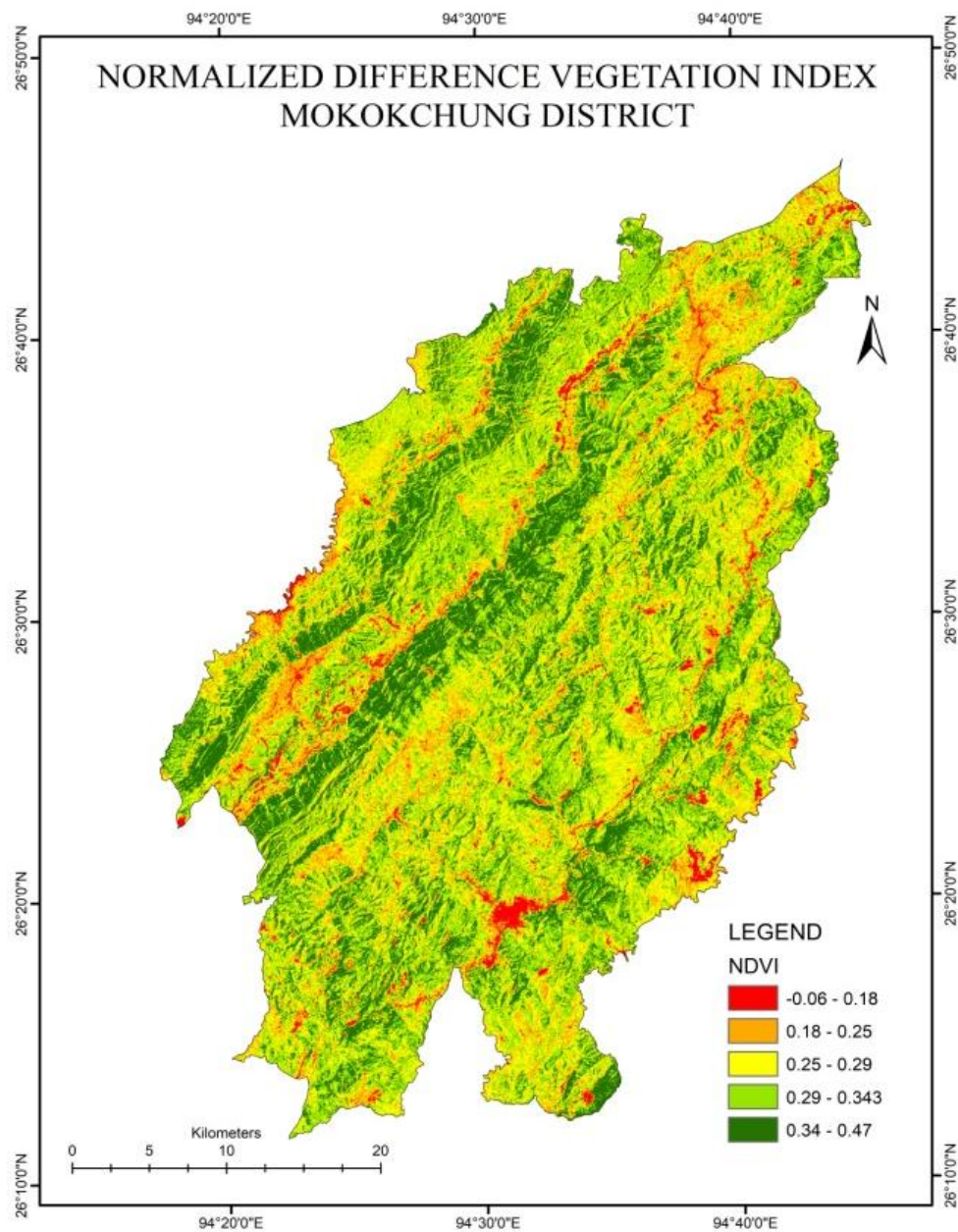


Figure 4.4: Normalized Difference Vegetation Index Map of Mokokchung District.

4.1.2.10. Slope Aspect: Aspect, or the orientation of slope faces relative to the sun, is a crucial geo-environmental factor influencing the frequency and distribution of landslides (Dahal et al., 2008; Ruff & Czurda, 2008). In hilly terrains, slope aspect affects key environmental variables such as solar radiation, soil moisture, vegetation cover, and the intensity of orographic precipitation. These factors in turn, directly impact slope stability and the likelihood of landslide occurrences (Goetz et al., 2015; Pourghasemi et al., 2012). In the study area, slope aspect is classified into ten categories (Figure 3.4) in a clockwise direction: Flat (-1), North (0° - 22.5°), Northeast (22.5° - 67.5°), East (67.5° - 112.5°), Southeast (112.5° - 157.5°), South (157.5° - 202.5°), Southwest (202.5° - 247.5°), West (247.5° - 292.5°), Northwest (292.5° - 337.5°), and North (337.5° - 360°). The weight assigned to slope aspect for the Mokokchung district, as determined using the Analytical Hierarchy Process (AHP), is 0.017. The pair-wise comparison scale used for evaluating different slope aspects ranges from 0 to 9.

4.1.3. Analytical Hierarchy Process: The Analytical Hierarchy Process (AHP) method introduced by Saaty (1980) has been used to find the relative weight and priority of the causative factors and sub factors of landslide in the study area. AHP is one of the multi criteria decision making (MCDM) methods of measurement through pair-wise comparisons and relies on the judgments of the experts to derive priority scales (Saaty, 2008). AHP uses pair-wise comparisons and matrix algebra to weight criteria. The three principal elements of AHP include hierarchy construction, priority analysis, and consistency verification. In carrying out the pair-wise comparison, the causative factors are assessed against each other using the scale of relative relevance (Table 4.1) on a scale of 1-9 basing on their relative significance in inducing instability to the slope (Yagi 2003).

Table 4.1: Ordinal scale representing preference of judgment (Saaty, 1977)

Scale	Level of Preferences	Description
1	Equally Important	The contribution of the two factors is equally important
3	Slightly Important	One factor is slightly influential over the other
5	Quite Important	One factor has more influence than the other
7	Extremely Important	One factor is significantly influential over the other
9	Absolutely Important	Difference between the two factors is extremely significant
2,4,6,8	Intermediate Judgment Values	In between two judgments

Table 4.2: Random consistency index (RI) (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.5	0.9	1.1	1.2	1.3	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5
I			8	0	2	4	2	1	5	9	1	3	6	7	9

To guarantee that the judgments are consistent, Consistency Verification is incorporated to measure the degree of consistency among the pair-wise comparisons by computing the Consistency Ratio (CR) formulated by Kolat et al., 2012). A consistency Ratio (CR) of 0.1 or less is considered in recognizing the class weights and is calculated using the formula:

$$\text{Consistency Ratio} = \frac{\text{Consistency Index}}{\text{Random Index}}$$

Consistency Index (CI) is in turn measured through the formula:

$$CI = \frac{\lambda_{\max} - 1}{n - 1}$$

Where $\lambda_{\max}$ is the major eigen value, n is the order of the matrix, CI is the Consistency Index of the judgment matrix, RI is the consistency Index of the randomly generated pair-wise matrix and its value depends on the number of selected variables in the matrix as given in table 4.3.

The calculated Consistency Ratio (CR) of this study is 0.011, indicating a consistent comparison of matrices and the weights are deemed appropriate for landslide hazard assessment.

Table 4.3: AHP pair-wise comparison matrix, weights, random index value and consistency ratio of spatial data (Saaty, 1990).

Factors	S	R	LD	GL	LU	DD	GM	NDVI	EL	SA	Weights
Slope (S)	1	1	3	3	5	3	4	7	7	8	0.234
Rainfall (R)	1	1	2	2	5	4	3	6	6	7	0.231
Lineament Density (LD)	0.5	0.5	1	2	4	3	3	6	5	7	0.161
Geology (GL)	0.333	0.333	0.5	1	3	2	2	5	4	6	0.109
Land Use Pattern (LU)	0.2	0.2	0.25	0.333	1	0.5	0.5	3	0.5	4	0.042
Drainage Density (DD)	0.25	0.25	0.333	0.5	2	1	1	4	3	5	0.072
Geomorphology (GM)	0.25	0.25	0.333	0.5	2	1	1	3	4	5	0.072
NDVI	0.143	0.143	0.167	0.2	0.333	0.25	0.25	1	0.333	2	0.022
Elevation (EL)	0.167	0.167	0.2	0.25	2	0.333	0.333	3	1	3	0.039
Slope Aspect (SA)	0.125	0.143	0.143	0.167	0.25	0.2	0.2	0.5	0.333	1	0.017
Consistency Ratio											0.0356

$\lambda_{\max} = 10.477$, Consistency Index=0.053

Table 4.4: Weights and rating matrix used for reclassification and overlay of thematic layers of landslide causative factors and their sub-factors.

Sl. No.	Factors	Classes	Rating	Weights
1.	Slope Morphometry (in Degree)	0-9 10-17 18-24 25-33 34-70	1 2 3 6 8	0.234
2.	Rainfall (in mm)	954-999 999-1023 1023-1043 1043-1061 1061-1094	2 3 5 7 9	0.231
3.	Lineament Density	0-29 30-83 84-140 150-260 270-570	3 5 6 8 9	0.161

Sl. No.	Factors	Classes	Rating	Weights
4.	Geology	Tipam Sandstone formation	4	0.109
		Surma Group	6	
		Disang Formation	8	
		Barail Group	9	
5.	Drainage Density	Below 1	2	0.072
		1-3	3	
		3-5	5	
		Above 5	6	
6.	Geomorphology	Highly Dissected Hills and Valleys	8	0.072
		Low Dissected Hills and Valleys	7	
		Moderately Dissected Hills and Valleys	6	
		Pediment Pediplain Complex	4	
		Alluvial Plains	1	
7.	Land Use Pattern	Dense Forest Land	3	0.042
		Open Forest Land	4	
		Agricultural Land	5	
		Built Up Area	7	
		Barren Land	9	
8.	Elevation	108-343	2	0.039
		344-557	4	
		558-784	6	
		785-1046	7	
		1047-1602	8	
9.	NDVI	-0.06-0.18	6	0.022
		0.18-0.25	5	
		0.25-0.29	3	
		0.29-0.34	2	
		0.34-0.47	1	
10.	Slope Aspect	Flat	0	0.017
		North	8	
		North-east	9	
		East	9	
		South-east	7	
		South	8	
		South-west	9	
		West	5	
		North-west	6	

Table 4.5: Landslide hazard zonation attributes

Landslide Zones	hazard	Area		Geomorphological characteristics of respective hazard zone
		Km ²	%	
Low		381.43	23	Low-lying alluvial plains, broad valley floors and stable piedmont surfaces
Moderate		729.62	45	Moderately elevated and transitional terrains, mid-slope regions and moderately dissected hills
High		381.88	24	Steep and rugged terrain, foothills, intermontane valleys and mid-level structural terraces.
Very High		121.74	8	High elevation, steep strike ridges and highly dissected structural hills and valleys
Total		1611.67	100	All of the above

4.1.4. Spatial Variability of Landslide Hazard Zonation: In the present study, the spatial relationship between field landslide occurrences and causative factors including Slope, Rainfall, Lineament, Geology, Land Use pattern and Geomorphology were assessed using AHP combined with GIS environment. The produced Landslide Hazard Zonation map illustrates four distinct degrees of landslide hazard potential in Mokokchung district, Nagaland: Low, Moderate, High and Very High Hazard Zones (Figure 4.5).

Areas of low landslide hazard: Low hazard zone includes the areas with mild slope gradients ($<20^\circ$) such as the low lying alluvial plains bordering Assam mostly along the northern and outer regions of the district as depicted in Figure 4.5. This zone is characterized by gentle slope gradients, low relief, and well vegetated valley plains (Table 4.5). It covers approximately 23% (381.43 km²) of the total study area. No landslide features were observed in this zone, likely suggesting stable terrain conditions.

Areas of moderate landslide hazard: Moderate hazard zone have been identified in regions with elevations ranging between 300 and 600 m, including river valleys, downslope terrain, and transitional belt-like regions across mid-elevation hills as

depicted in Figure 4.5. These zones are partly associated with river terraces and adjacent slopes. They are characterized by intermediate slope gradients, moderate vegetation cover, and limited levels of human disturbance (Table 4.5). It covers approximately 45% (726.62 km²) of the total study area.

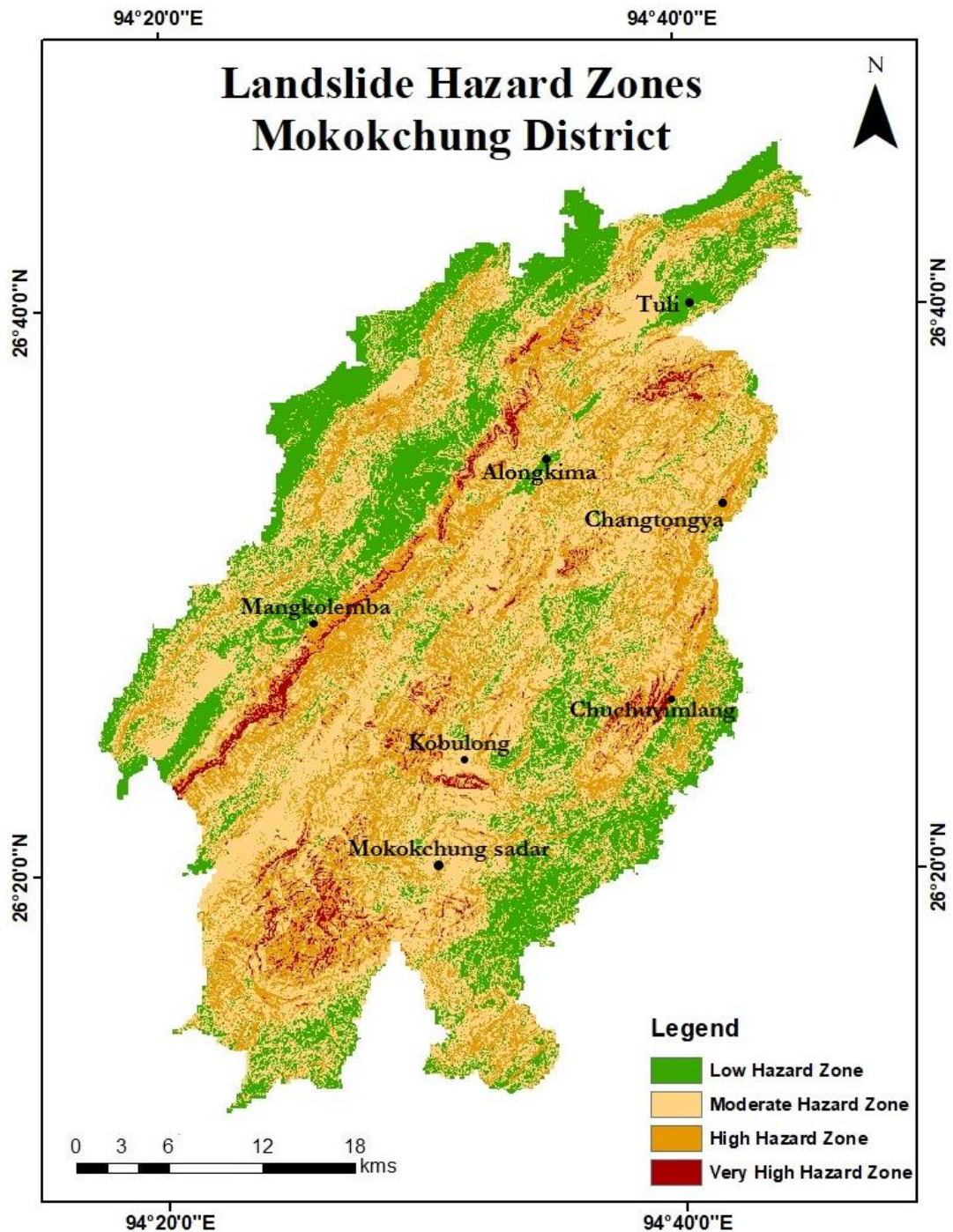


Figure 4.5: Landslide Hazard Zonation Map of Mokokchung District.

Areas of high landslide hazard: High hazard zone have been identified in the central and southwestern parts of the district with high elevations as depicted in Figure 4.5. This zone is characterized by steep and rugged terrain, foothills, intermontane valleys and mid-level structural terraces (Table 4.5). Human activities such as deforestation, together with the ongoing geomorphological instability, further increase the occurrence of landslides in these areas. This zone is found across much of the study area and covers approximately 24% (381.88 km²) of the total area.

Areas of very high landslide hazard: Very high hazard zone is the most unstable terrain within the district and is more localized in nature. These areas form long patches as depicted in Figure 4.5 and are mainly found in steep and highly dissected hill regions, particularly in the central and southern parts of the district. These areas are characterized by very steep slopes, unconsolidated materials, and active geomorphological processes (Table 4.5). Vegetation cover in this zone is mostly sparse, and the growing human activities further leading to slope instability. This zone covers approximately 8% (121.74 km²) of the total area.

4.2. Flash Flood Hazard in Mokokchung District

Flash floods are among the most destructive natural hazards worldwide, primarily because of their sudden onset, rapid rise in water levels, and severe impacts on both natural and human systems. These events typically arise from the interaction of intense, short duration rainfall with the topographic, geological, and surface characteristics of a drainage basin (Costa, 1987; Youssef et al., 2009; Kharraz et al., 2012; Karmokar & De, 2020). High intensity rainstorms, often lasting only a few hours, can generate large volumes of runoff, leading to abrupt increases in river and stream discharge (Penna et al., 2013). Flash floods typically occur within minutes to six hours following heavy precipitation and can rapidly inundate areas that were previously dry, resulting in extensive damage to life, property, and infrastructure (Hong et al., 2012). From a geomorphological perspective, such events are capable of inducing intense erosion, large scale sediment transport and deposition, thereby significantly altering channel morphology and reshaping the surrounding landscape (Reid, 2014). Their impacts are particularly severe in mountainous and hilly regions where steep slopes,

fragile geological formations, and high drainage density accelerate runoff concentration and increase flow velocity. The extreme severity of flash floods is largely attributed to their localized nature and short response time, especially when intense rainfall occurs over already saturated soils in rugged terrain (Georgakakos & Hudlow, 1984).

As a result, flash floods are associated with disproportionately high mortality rates comparing to other flood types. Jonkman (2005) reported that while mortality rates for general floods are typically below 1 percent, flash floods can approach nearly 4 percent, accounting for an estimated average of more than 5000 fatalities worldwide each year. In India, one of the most flood prone countries experiences flash floods during the monsoon season, when daily rainfall often exceeds 150 mm, leading to widespread flooding and associated hazards (Goswami et al., 2006).

The eastern Himalayan region in particular, exhibits high susceptibility to flash floods owing to its distinctive environmental and geological conditions. Annual rainfall in this region ranges from approximately 1600 mm to 3400 mm, with intense monsoonal precipitation contributing significantly to flood occurrences (Rawat et al., 2011, 2012, 2012a, 2012b; Das, 2016; Shahiri, 2016; Barman et al., 2021). Moreover, the region is dominated by young and highly erodible rock formations composed mainly of sandstones, siltstones, and shales, fragmented and dynamically reshaping geomorphology, high soil erodibility, and a dense drainage network, all of which enhance its vulnerability to flash floods, erosion, landslides, debris flows, and slope failures. These floods have profound impacts on communities, socio-economic activities, wildlife, and the environment, particularly during the monsoon seasons (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; Das, 2016). Mokokchung district, located within this region, also experiences flash floods during the monsoon season due to its steep and rugged terrain, active tectonic settings, young and highly erodible geology, and dense drainage network. Therefore, assessing and mapping flash flood hazard zones in Mokokchung is essential for effective

preparedness and risk reduction strategies, enabling safe development planning by governmental agencies, communities, and stakeholders.

4.2.1. Methodology

4.2.1.1. Preparation of GIS spatial database: Flash flood susceptibility in Mokokchung district was assessed by analyzing a range of geophysical, topographical, hydro-meteorological, and ecological parameters. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at a spatial resolution of 30 m and were used to generate elevation, slope gradient, and wetness index layers, which are essential for understanding surface runoff behavior and flow accumulation patterns. Rainfall data covering a period of more than two decades (2003-2023) were collected from the CHRS Data Portal and supplemented with records from ground based meteorological stations operated by the Indian Meteorological Department (IMD) within and around Mokokchung district. These rainfall data were spatially interpolated using the Inverse Distance Weighting (IDW) method to produce continuous rainfall distribution maps across the study area. Drainage characteristics including stream order and drainage density, were derived through topographic and hydrological analyses conducted within a GIS environment using the DEM. In addition, river buffer zones were generated to evaluate the proximity of different areas to river channels, thereby identifying zones with increased risk for flood inundation. The geological and geomorphological framework of the district was mapped using Survey of India (SOI) topographical sheets and subsequently validated through field observations and Google Earth imagery. This approach facilitated the identification of terrain types, landforms, and structural features that influence flood susceptibility. Ecological factors, such as land use and land cover were extracted from recent Landsat satellite imagery with a spatial resolution of 30 m. The Normalized Difference Vegetation Index (NDVI) was computed to assess vegetation density and its role in regulating surface runoff and infiltration. All thematic layers were prepared, standardized, and integrated within a GIS environment to evaluate the combined influence of these factors on flash flood hazard susceptibility in Mokokchung district.

4.2.1.2. AHP based integration of landslide factors in GIS for hazard zonation:

Integrating AHP with GIS to analyze factors influencing flood risk such as slope, land use, proximity to streams and drainage lines, rainfall intensity, elevation, curvature, and lithological characteristics establishes a comprehensive geographic decision support framework (Haokip et al., 2022; Al-Taani et al., 2023; Khosravi et al., 2019; Edamo et al., 2022). Using the AHP method, a pair-wise comparison matrix was constructed in which each factor was systematically compared with every other factor to determine its influence on flash flood occurrence. These comparisons were done using Saaty's nine-point scale, where a value of 1 represents equal importance where each factor was compared against every other factor to assess their relative importance in contributing to flash flood susceptibility in Mokokchung. The comparisons were conducted using Saaty's nine point scale, where a score of 1 denoted equal importance and a value of 9 represent extreme dominance of one factor over another. This pair-wise comparison matrix was then used to compute normalized weights for each factor by deriving the principal eigenvector. To ensure the reliability and logical consistency of the judgments, the Consistency Ratio (CR) was calculated. A CR value of less than 0.1 was considered acceptable, indicating that the comparisons were consistent and methodologically sound. The final weights, representing the relative contribution of each causative factor to flash flood susceptibility, were assigned to their respective thematic layers. These weighted layers were integrated using a weighted linear combination through GIS based overlay analysis to produce the flash flood hazard zonation map. The resulting map classifies Mokokchung district into different hazard zones, ranging from very low to very high susceptibility.

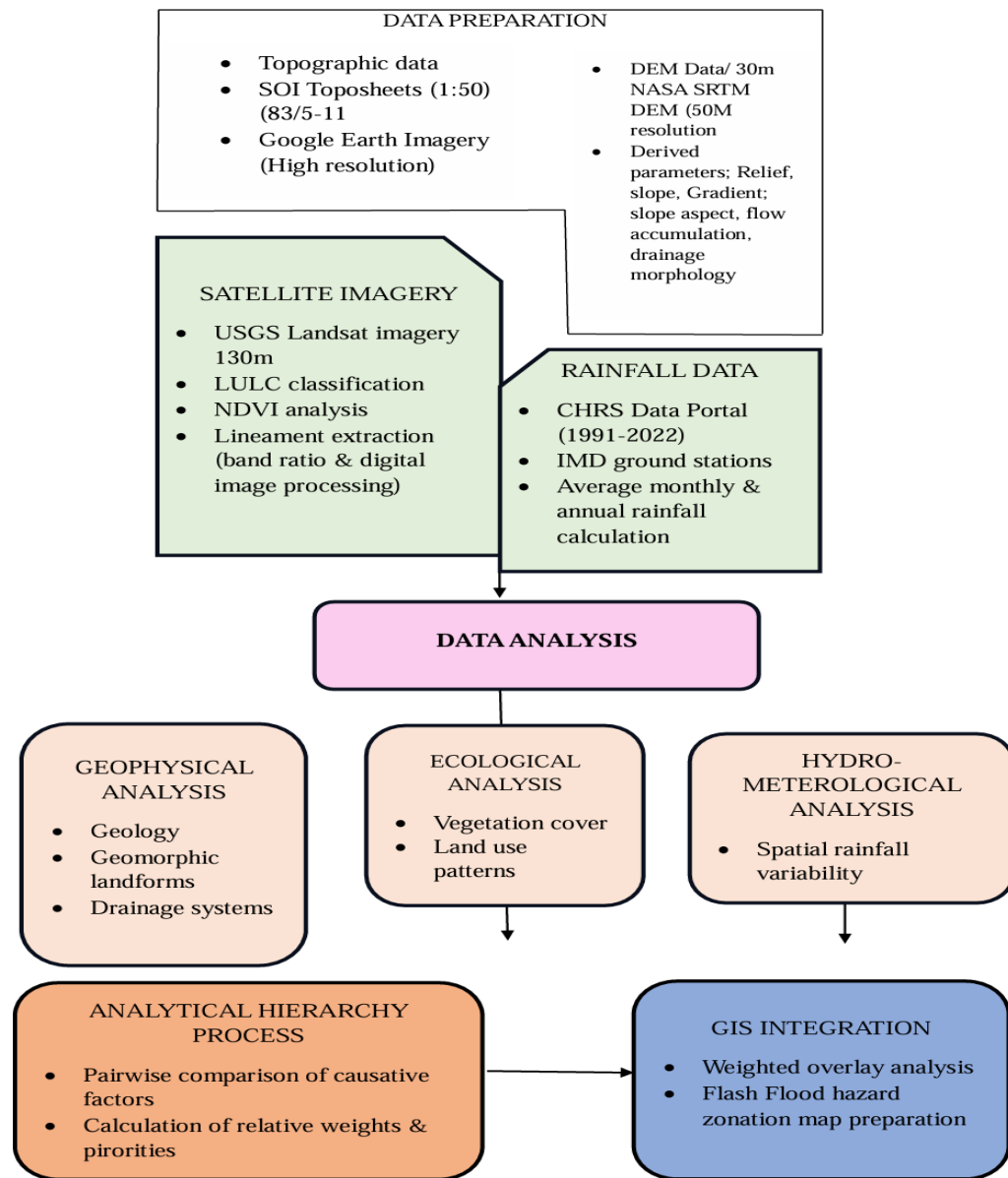


Figure 4.6: Methodology for flash flood hazard zonation in Mokokchung District.

In this study, a weighted linear combination model was established to evaluate flood risk by determining the relative importance of key variables. The Analytical Hierarchical Process (AHP) proposed by Saaty (1980), was employed to conduct pairwise comparisons of eleven criteria including elevation, rainfall, slope gradient, wetness index, drainage order, river buffer distance, drainage density, land-use pattern, NDVI, geology and geomorphology, using a nine point scale after establishing the hierarchical structure. Each criterion's importance was determined by systematically

comparing it with others in the matrix. The resulting pair-wise comparison matrix was used to derive the weights of each criterion from the principal eigenvector presented in Table 4.6. The calculated Consistency Ratio (CR) of this study is 0.061, indicating a consistent comparison of matrices and the weights are deemed appropriate for landslide hazard assessment.

Table 4.6: AHP pair-wise comparison matrix, weights, random index value and consistency ratio of spatial data (Saaty, 1990).

Factors	EL	RF	SG	WI	DO	RB	DD	LU	GM	GL	Weights
Elevation (EL)	1	2	3	4	5	6	7	8	9	10	0.290
Rainfall (RF)	1/2	1	2	3	4	5	6	7	8	9	0.209
Slope Gradient (SG)	1/3	1/2	1	2	3	4	5	6	7	8	0.151
Wetness Index (WI)	1/4	1/3	1/2	1	2	3	4	5	6	7	0.109
Drainage Order (DO)	1/5	1/4	1/3	1/2	1	2	3	4	5	6	0.078
River Buffer Distance (RB)	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	0.056
Drainage Density (DD)	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	0.040
Land Use Pattern (LU)	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	0.028
Geomorphology (GM)	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	0.020
Geology (GL)	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.015
Consistency Ratio											0.061

$$\lambda_{\max} = 10.82, \text{ Consistency Index} = 0.092$$

Table 4.7: Weights and rating matrix used for reclassification and overlay of thematic layers of flash flood causative factors and their sub factors.

Sl. No.	Factors	Classes	Rating	Weights
1.	Elevation	108-343	8	0.281
		344-557	7	
		558-784	6	
		785-1046	4	
		1047-1602	2	
2.	Rainfall (in mm)	1061-1094	9	0.206
		1043-1061	7	
		1023-1043	5	
		999-1023	2	
		954-999	3	

Sl. No.	Factors	Classes	Rating	Weights
3.	Slope Morphometry (in Degree)	0-9	8	0.152
		10-17	6	
		18-24	3	
		25-33	2	
		34-70	1	
4.	Topographic Wetness Index	Very High	9	0.111
		High	7	
		Moderate	5	
		Low	3	
		Very Low	1	
5.	Drainage pattern and Order	5 th Order	8	0.082
		4 th Order	7	
		3 rd Order	4	
		2 nd Order	2	
		1 st order	1	
6.	Distance from the River	0-500	9	0.059
		500-1000	7	
		1000-1500	5	
		1500-2000	3	
		>2000	1	
7.	Drainage Density	Above 5	7	0.043
		3-5	5	
		1-3	2	
		Below 1	1	
8.	Land Use pattern	Barren Land	9	0.031
		Built Up Area	7	
		Agricultural Land	5	
		Open Forest Land	4	
		Dense Forest Land	3	
9.	Geology	Tipam Sandstone formation	9	0.016
		Surma Group	8	
		Disang Formation	6	
		Barail Group	4	
10.	Geomorphology	Alluvial Plains	9	0.012
		Pediment Pediplain Complex	7	
		Low Dissected Hills and Valleys	4	
		Moderately Dissected Hills and Valleys	2	
		Highly Dissected Hills and Valleys	1	

4.2.2. Flash flood influencing Parameters: For flash flood susceptibility mapping of the study area, ten major influencing parameters of flash flood were identified and incorporated. These include elevation, rainfall, slope gradient, wetness index, drainage order, river buffer distance, drainage density, land use pattern, geomorphology and geology. The continuous factors further categorized into different sub factors to represent their spatial variability. Detailed description for each parameter has been discussed as under:

4.2.2.1. Elevation: Elevation plays a crucial role in influencing runoff generation, flow direction, and water depth (Ogato et al., 2020). In rugged mountainous regions, elevation governs fluvial processes because discharge volumes depend on the upstream catchment area. Water naturally accumulates from higher to lower elevations, increasing the risk of flash flooding in low lying areas where rainwater simultaneously converges. The elevation of Mokokchung ranges from approximately 108 meters to 1905 meters mean sea level (Figure 2.2). The relief factor for flash flood was assigned a weight value of 0.281. Based on the altitudinal range, pair-wise comparison matrix for the five stratified classes are: 8 for elevations ranging between 108-364, 7 for elevations ranging between 365-623, 6 for elevations ranging between 624-853, 4 for elevations between 854-1132, and 2 for elevation ranging between 1132-1905.

4.2.2.2. Rainfall Pattern: Rainfall is a major factor contributing to the occurrence of flash floods. High intensity rainfall leads to increased surface water flow, thereby elevating the risk of flash flooding. There is a strong correlation between precipitation levels and river discharge, which in turn amplifies flood hazards. In the study area, the tendency for heavy rainfall makes it particularly susceptible to flash flood events. Rainfall variability indicates that the average annual rainfall of Mokokchung District ranges from 954-1094 mm (Figure 4.2). The weight value of rainfall in the Analytical Hierarchy Process (AHP) is 0.206. The scale for pair-wise matrix of average annual rainfall has been assigned as follows: 2 for rainfall between 954-999 mm, 3 for rainfall between 999-1023 mm, 5 for rainfall between 1023-1043 mm, 7 for rainfall between 1043-1061 mm, and 9 for rainfall between 1061-1094 mm.

4.2.2.3. Slope gradient: The slope of a land surface plays a crucial role in determining the velocity of surface water flow. There is a direct relationship between slope gradient and surface water velocity: as the slope decreases, the velocity of surface water also decreases, resulting in a greater accumulation of water on the land surface, which enhances the likelihood of flooding (Das, 2021). The gradient of a slope influences not only the speed but also the volume and direction of both surface runoff and subsurface drainage reaching a particular location. Furthermore, slope angles define the relationship between slope shape and other factors such as lithology, geological structure, soil type, and drainage characteristics. Areas with low slope gradients are generally more prone to flooding because rainwater or overflow from rivers tends to accumulate in such regions. In contrast, steep slopes facilitate rapid drainage, preventing water accumulation and thus reducing flood risk (Tariq et al., 2022). Weightage value of slope gradient calculated through Analytical Hierarchy Process (AHP) model stands at 0.152, while the scale for pair-wise matrix has been assigned in accordance with the steepness of the slope i.e. 8, 6, 3, 2 and 1 for very gentle, gentle, moderate, steep and very high slopes respectively.

4.2.2.4. Topographic wetness index: Topographic wetness index (TWI) plays a crucial role in hydrological studies, especially in relation to groundwater recharge drought variability, soil moisture distribution, runoff processes, and flood hazard assessment. In this study, TWI was computed to assess the spatial variability of runoff and flood risk across the study area. The TWI value ranges from 1 to 5, which has been categorized into five classes (Figure 4.7). The Analytical Hierarchy Process (AHP) weight value of TWI for the study area stands at 0.111, whereas the scale for pair-wise matrix stands 1, 3, 5, 7, and 9 for topographic wetness index very low, low, moderate, high and very high.

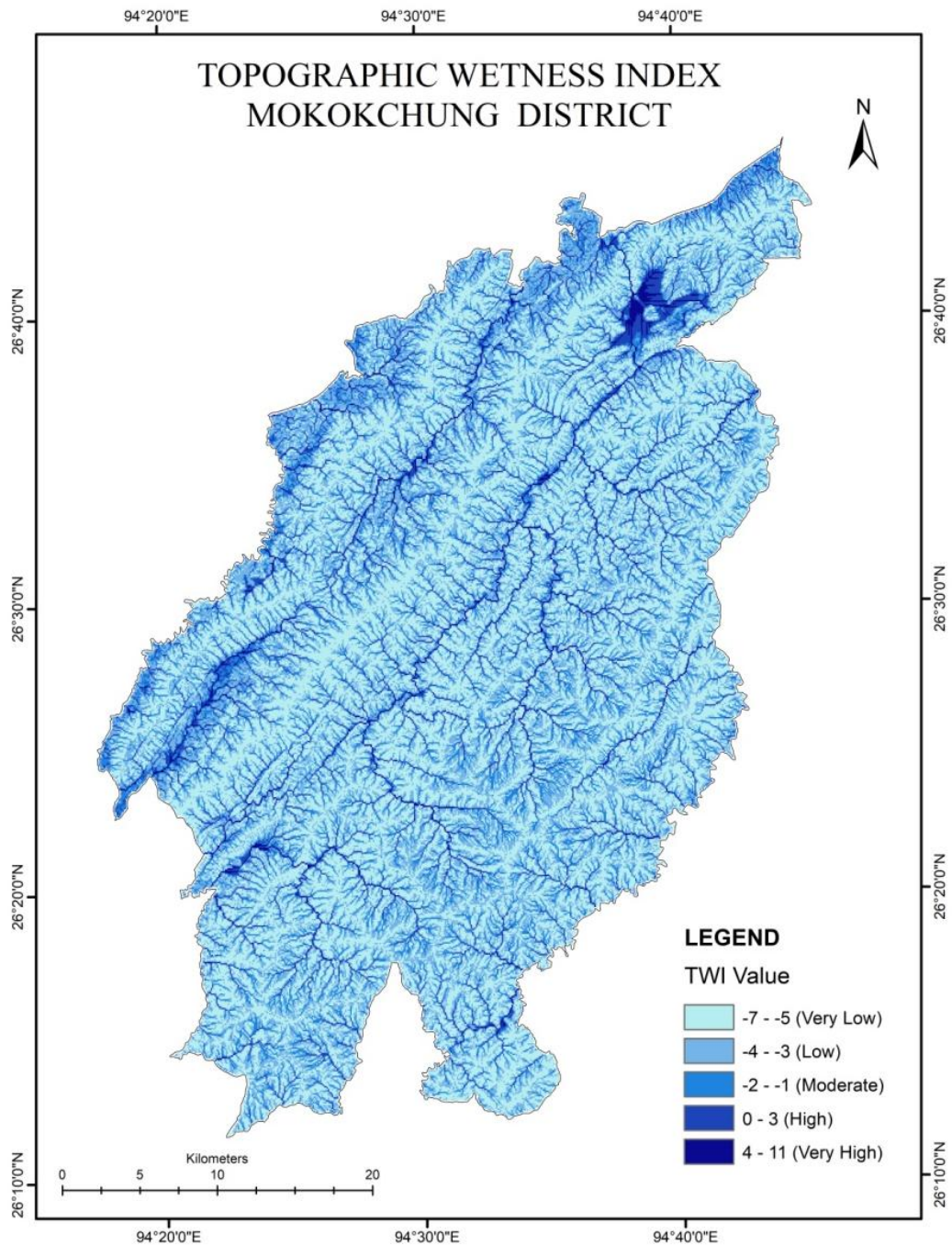


Figure 4.7: Topographic Wetness Index Map of Mokokchung District.

4.2.2.5. Drainage pattern and order: Drainage pattern and stream order play a vital role in controlling the occurrence and intensity of flash floods. The configuration of a drainage network governs how surface runoff is concentrated and routed toward the main channels of a basin. Certain drainage patterns, particularly dendritic networks with high drainage density facilitate rapid convergence of flow, leading to quick rises

in discharge and sharp flood peaks (Horton, 1945). Lower order streams are generally more numerous and widely distributed throughout a catchment. These streams collect runoff from smaller contributing areas and rapidly convey it downstream into higher order channels. Such high network connectivity accelerates the accumulation of runoff, thereby increasing flash flood potential, especially in small and steep drainage basins (Costa, 1987; Jha et al., 2021).

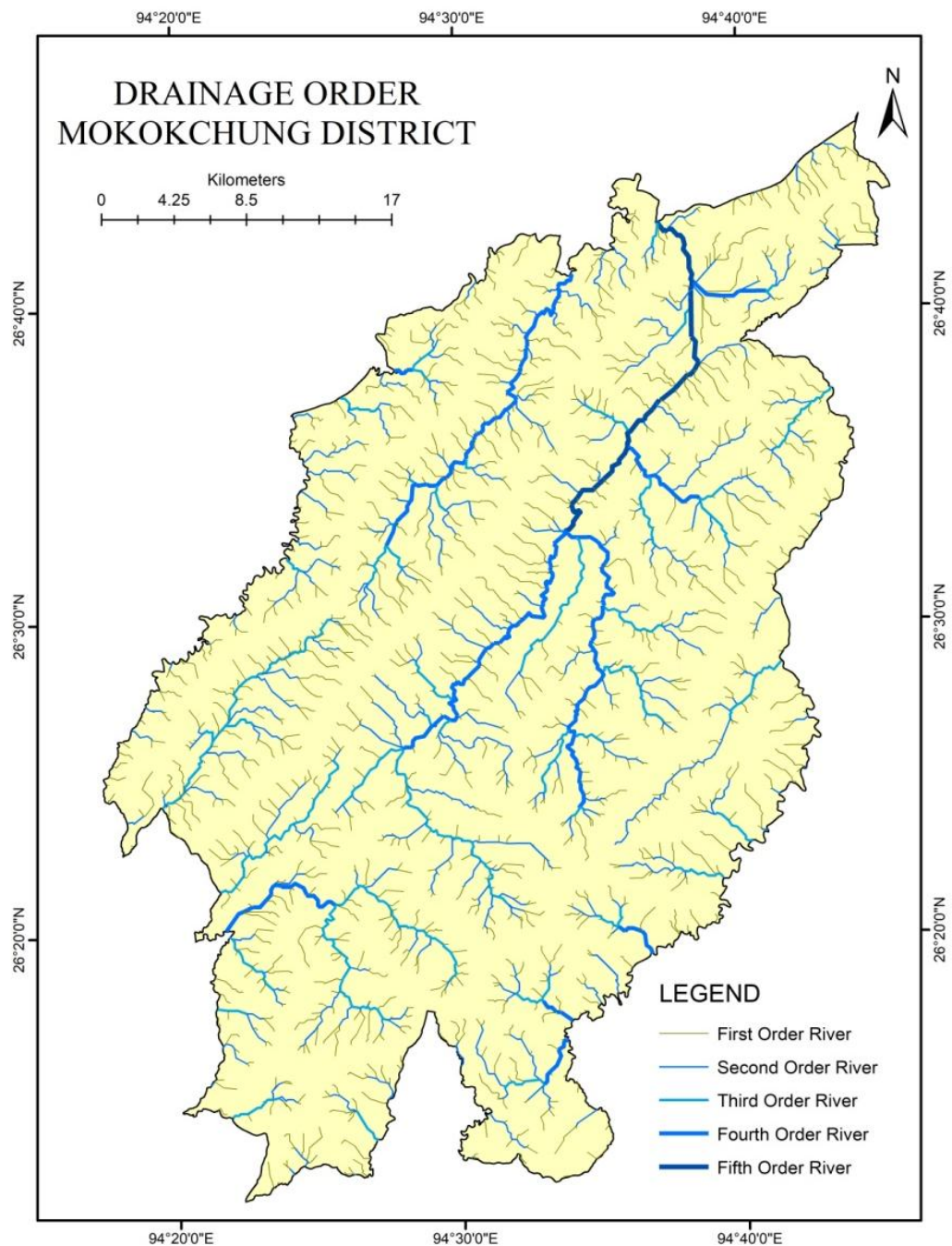


Figure 4.8: Drainage Order Map of Mokokchung District.

Consequently, basins characterized by high drainage density and a dominance of lower order streams typically exhibit short lag times and steep hydrograph peaks, which are defining features of flash flood events. The digital elevation model (DEM) based drainage pattern map of Mokokchung district shows 1 to 5 order streams across the study area as shown in Figure 4.8. The Analytical Hierarchy Process (AHP) weight value of drainage order for the study area stands at 0.082, whereas the scale for pair-wise matrix stands 1, 2, 4, 7 and 8 for drainage order 1, 2, 3, 4 and 5 respectively.

4.2.2.6. Distance from the river: Distance from the river is a critical determinant in assessing flash flood susceptibility within a river basin. Proximity to rivers significantly increases the risk of flash flooding, as riverine areas act as major pathways for rapid water flow and accumulation during intense rainfall events. Areas closer to rivers are more vulnerable due to the immediate inundation caused by rising water levels and the direct conveyance of runoff from surrounding catchments. Studies have shown a reciprocal relationship between flood hazard and proximity to river channels, with flood vulnerability decreasing as the distance from the river increases (Fernández & Lutz, 2010; Souissi et al., 2020). This relationship is particularly relevant for flash floods, where water from higher elevations swiftly converges at lower elevations near river courses, resulting in sudden and severe flooding in adjacent zones. The Analytical Hierarchy Process (AHP) weight value of river buffer zones for the study area stands at 0.059, whereas the scale for pair-wise matrix stands at 9, 7, 5, 3, and 1 for core zone, outer core zone, intermediate zone, outer zone and remote zone respectively.

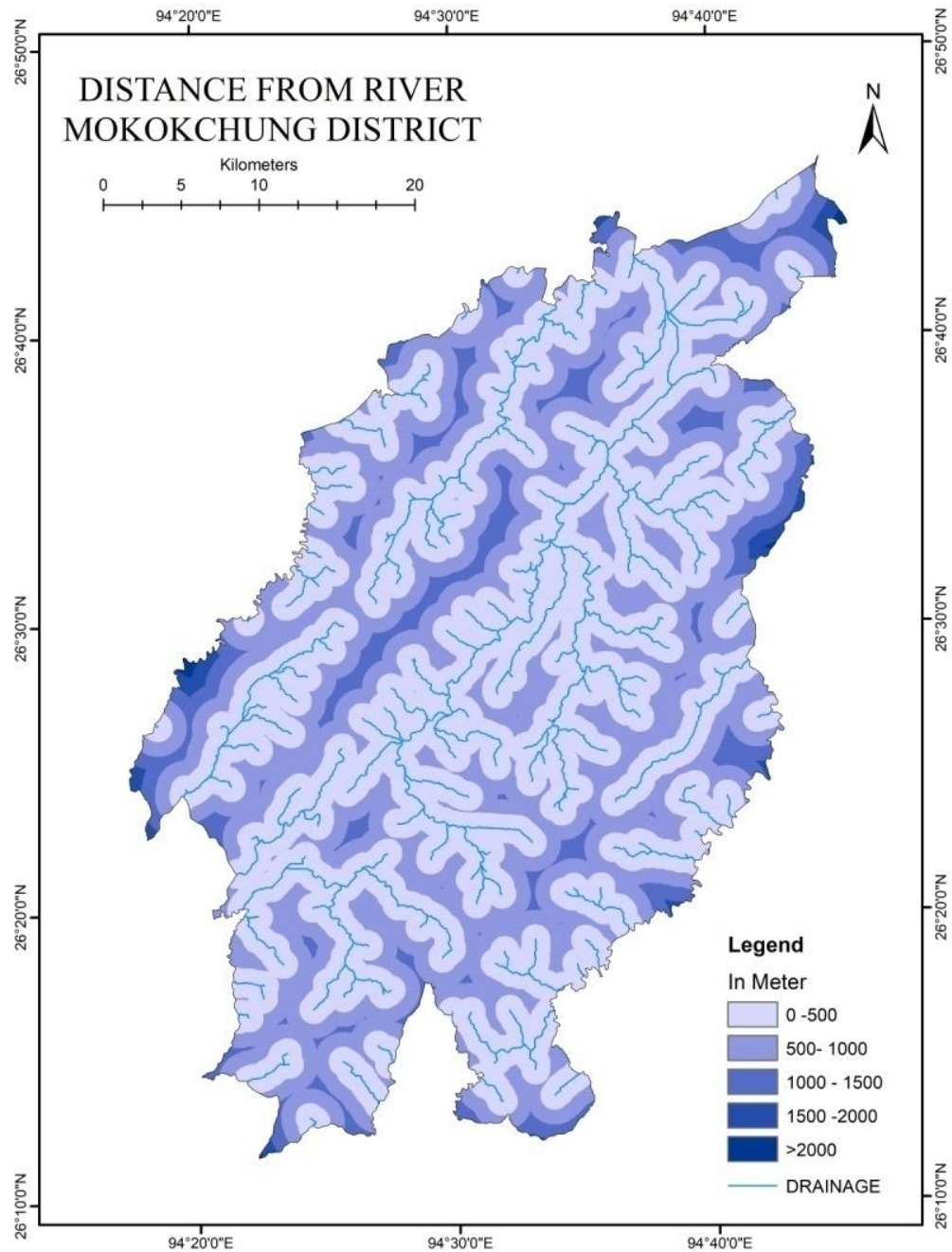


Figure 4.9: River Distance Map of Mokokchung District.

4.2.2.7. Drainage Density: Defined as the total length of streams and rivers per unit area, high drainage density indicates a dense network of channels that facilitates rapid conveyance of surface runoff. Regions with higher drainage density are more prone to flash flooding because the extensive network enables quick water accumulation and

flow during intense rainfall events. This leads to reduced infiltration and increased surface runoff, amplifying the likelihood of sudden flooding. Studies have shown a direct correlation between drainage density and flood occurrence, where areas with dense drainage networks experience heightened flood risk due to the efficient concentration and movement of water (Kalédjé et al., 2019). The spatial variability of drainage density of the study area have been classified into four different classes (Figure 3.8) and assigned weight values to their significance to flood hazard. The Analytical Hierarchy Process (AHP) weight value of drainage density for the study area stands at 0.043, whereas the scale for pair-wise matrix stands 1, 2, 5 and 7 for drainage density below 1, 1-3, 3-5 and above 5 km/km² respectively.

4.2.2.8. Land Use pattern: Land use and land cover significantly influence flash flood susceptibility. Vegetated areas, such as grasslands and crop fields, enhance soil infiltration and reduce runoff, lowering flood risk. In contrast, bare lands and impervious surfaces like roads and buildings reduce water absorption, leading to rapid surface runoff and increased flood severity. Thus, LULC determines how effectively rainfall is absorbed or channeled as runoff, making it a key factor in flash flood occurrence. The Analytical Hierarchy Process (AHP) weight value of the land use pattern for the study area stands at 0.031, whereas the scale for pair-wise matrix stands at 3, 4, 5, 7, and 9 for dense forest, open forest, agricultural, built-up and barren land (wasteland) respectively.

4.2.2.9. Geology: Geology significantly influences flash flood susceptibility by determining the permeability and infiltration capacity of an area. Permeability, which significantly affects flood susceptibility, is controlled by the lithological characteristics and rock types of an area, as these determine the rate and extent of water movement through the subsurface (Miklós & Hrnčiarová, 2002, Kader et al., 2024). The type and structure of underlying geological materials are crucial in controlling how rainfall is absorbed or converted into surface flow, affecting flash flood occurrence. The weight value of geology for the study area, as determined by the Analytical Hierarchy Process (AHP) is 0.016. The pair-wise matrix scale for geology

of Barail group, Disang group, Surma group and Tipam group has been assigned 4, 6, 8 and 9 accordingly.

4.2.2.10. Geomorphology: Geomorphology, which includes landform characteristics such as slope, elevation, and valley shape, plays a crucial role in flash flood susceptibility. Steep slopes and narrow valleys accelerate surface runoff, increasing the speed and intensity of flash floods (Rahmati et al., 2016; Singh et al., 2018). Rugged terrains with high relief facilitate rapid water flow towards lower elevations, enhancing flood risk (Ogato et al., 2020). Therefore, geomorphological features directly influence how rainfall is collected, concentrated, and discharged within a catchment, making them key determinants in flash flood occurrence. The weight value of geomorphology in the Analytical Hierarchy Process (AHP) is 0.012. The scale for pair-wise matrix of geomorphological units has been assigned as follows: 9 for Alluvial Plains, 7 for Pediment Pediplain Complex, 4 for lowly dissected structural Hills and Valleys, 2 for moderately dissected structural Hills and Valleys and 1 for highly dissected structural Hills and Valleys.

4.2.3. Spatial Variability of Flash Flood Hazard Zonation: Using overlay analysis, flood susceptibility zones in Mokokchung district were delineated in a GIS environment by integrating factor weights and class values derived from the Analytic Hierarchy Process (AHP). A weighted summation of all conditioning factors produced a comprehensive susceptibility map, classifying areas based on their vulnerability to flooding. The final hazard zone map was derived by superimposing reclassified raster layers through weighted overlay operations in GIS software. The map identifies four levels of flood hazard across Mokokchung district: low, moderate, high and very high. Table 4.8 presents a detailed spatial distribution of flood susceptibility across Mokokchung district, wherein 2% of the total area is categorized as low, 45% as moderate, while 47% and 6% fall within high and very high susceptibility classes, respectively.

Table 4.8: Flash Flood hazard zonation attributes

Flood hazard Zones	Area		Geomorphological characteristics of respective hazard zone
	Km ²	%	
Low	32.89	2	High Elevation, strike ridges, steep dissected hills, minimal accumulation
Moderate	731.90	45	Moderate slopes, transitional landforms and mid-elevation hills
High	763.11	47	Foothills, intermontane valleys, mid-level terraces, runoff convergence zones.
Very High	84.90	6	Low-lying alluvial plains, fluvial plains, piedmont areas, close to rivers
Total	1612.8	100	All of the above

Areas of low flash flood hazard: Areas under low flash flood hazard zone are found in small, scattered parts of Mokokchung district, mainly in the southern and southeastern valleys as depicted in Figure 4.10. These areas are characterized by high elevation, strike ridges, steep dissected hills with minimal accumulation (Table 4.8). The low hazard zone covers approximately 2% (29.89 km²) of the district's total area. Since these areas are away from major runoff paths, water drains more slowly, soils are deeper, and more rainwater can penetrate into the ground. As a result, occurrence of flash floods remains low, even during heavy rainfall.

Areas of moderate flash flood hazard: This zone is the most extensive and forms a nearly continuous belt across much of the district as depicted in Figure 4.10. It covers approximately 45% (728.90 km²) of the district's total area. These areas are characterized by moderate slopes, transitional landforms, and mid elevation regions (Table 4.8). The terrains in these areas have sharp gradients and well drained surfaces, which allow rainfall to flow quickly, thus limiting prolonged water accumulation. The presence of mainly first order streams, which carry smaller amounts of water, further lowers the risk of sudden flooding. As a result, even though these areas receive heavy rainfall, the chances of flash floods remain low due to rapid runoff and limited water storage.

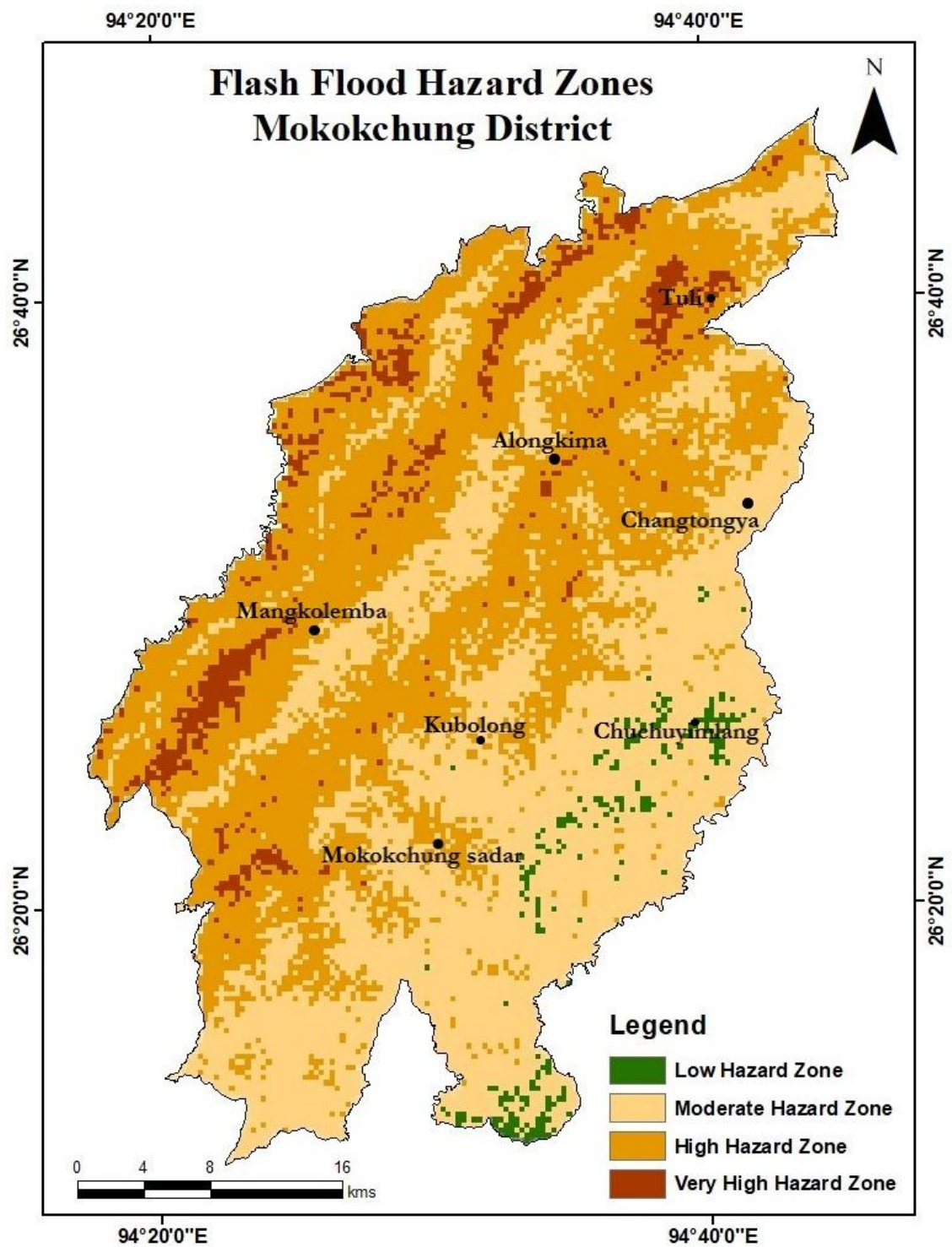


Figure 4.10: Flash Flood hazard Map of Mokokchung District.

Areas of high flash flood hazard: It covers a large portion of the district as depicted in Figure 4.10 and is found at mid elevation ranges and include moderate to steep slopes. It covers approximately 47% (762.15 km²) of the district's total area. Geomorphologically, these areas comprise river valleys, lower hill slopes, mid level river terraces, and foothill zones (Table 4.8) where surface runoff from higher areas flows down and gathers quickly. Because water moves rapidly into these zones and sometimes collects temporarily, the risk of flash flood is high, especially during peak monsoon season.

Areas of very high flash flood hazard: Very high hazard zones are mainly located along valley floors and low lying floodplains, especially in the northeastern parts of Mokokchung district as depicted in Figure 4.10 and also along major streams and rivers. It covers approximately 6% (84.90km²) of the district's total area. This zone is the most vulnerable and includes low lying alluvial plains, fluvial plains, piedmont areas, close to rivers (Table 4.8). These areas are linked to larger rivers, which carry more water and can overflow during heavy rainfall. The gentle slopes allow water to remain stagnant, and also the presence of settlements and agricultural activities further increases the damage caused by flash floods.

4.3. Seismotectonic Hazard in Mokokchung District

Earthquakes have repeatedly demonstrated why seismic factors must be taken seriously in infrastructure planning and disaster risk reduction. The various dangers linked to earthquakes commonly grouped under the term seismic hazards are central to earthquake engineering, a field concerned with understanding potential impacts and finding ways to reduce them. One of the most widely accepted tools for assessing site specific seismic risk is seismic microzonation (TC4-ISSMGE, 1999). Unlike broader macrozonation maps that outline hazard levels across large regions, microzonation focuses on much smaller areas and identifies variations in ground response within them. It produces detailed maps that divide a region into zones based on differences in expected seismic behavior. Because these maps draw on seismological, geological, and geotechnical data, they are especially useful for urban planning, structural design, and land-use regulation (Bell et al., 1987; Rau, 1994; Dai et al., 2001).

Seismic hazard analysis more generally, seeks to estimate the level of ground shaking that a particular site might experience. This information is essential for safe building design, disaster preparedness, and even insurance assessment. Two main approaches are commonly used. Deterministic Seismic Hazard Analysis (DSHA) considers specific earthquake scenarios, often focusing on the maximum credible event. In contrast, Probabilistic Seismic Hazard Analysis (PSHA) accounts for uncertainties in earthquake size and recurrence, estimating the probability that different levels of ground motion will be exceeded within a certain time frame.

The North Eastern Region (NER) of India is recognized as one of the most seismically active regions in the world (Das et al., 2012). Classified under seismic zone V, the highest hazard risk category in the Indian seismic zonation map (IS-1893, 2016), the region is tectonically influenced by the ongoing collision between the Indian and Eurasian plates to the north and the active subduction processes along the Indo-Burmese ranges to the east (Agrawal et al., 2022; Baro et al., 2018). This complex tectonic framework, combined with diverse geological units such as the Brahmaputra Valley, Mishmi Hills, Shillong-Mikir Plateau, and Tripura Fold Belt (Verma & Kumar, 1987), contributes to the region's heightened seismic vulnerability. The occurrence of major historical earthquakes, including the 1897 Assam earthquake (Mw 8.1) and the 1950 Assam-Tibet earthquake (Mw 8.6) further illustrate the potential for catastrophic seismic events in the region. Within this broader seismotectonic context, microzonation studies assume particular significance for Nagaland, and Mokokchung district in particular, where steep topography, fragile lithological conditions, and settlements concentrates along ridgelines and hill slopes considerably increase seismic risk. In such terrain, ground motion characteristics are controlled not only by earthquake magnitude and epicentral distance but also by local site effects, including soil thickness, valley fills, and weathered rock formations, which can significantly amplify seismic waves. Furthermore, secondary hazards such as earthquake induced landslides, rockfalls, and slope instability pose serious additional threats in these hilly environments, emphasizing the need for integrated seismic and geomorphological hazard assessments.

4.3.1. Methodology

To address the above mentioned challenges, this study presents a comprehensive seismotectonic framework for Mokokchung district through the integration of Geographic Information Systems (GIS) techniques, remote sensing application, and earthquake catalogue analysis. Primary geo-environmental parameters including drainage patterns, slope gradients, relief (derived from Digital Elevation Models), structural lineaments, geology, tectonic geomorphology and subsurface characteristics were extracted, analyzed, and spatially integrated within a GIS environment.

Topographical and satellite datasets, including Shuttle Radar Topography Mission (SRTM) digital elevation models and Google Earth Imagery, were georeferenced and co-registered with Survey of India (SOI) topographical sheets (Nos. 83J/2, J/3, J/6, J/7, J/9, J/10, J/11, J/14, and J/15) at a mapping scale of 1:50,000 to ensure spatial consistency. Earthquake data spanning the period 1980-2024 were compiled from both primary and secondary sources and incorporated into the GIS database. The dataset was drawn from major seismological agencies, including International Disaster Database (EM-DAT), Indian Meteorological Department (IMD), Indian Seismological Centre (ISC), CSIR-Northeast Institute of Science and Technology, United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA). Since seismic hazards in a region can be influenced not only by local but also by distant earthquakes, it is important to consider past events from surrounding areas when compiling an earthquake catalogue (Kumar et al., 2016a, 2017). Accordingly, for the present study on Mokokchung district, earthquake data were compiled within the longitude range of 92°E-97°E Longitude and the latitude range of 24°N-28°N Latitude, in order to include both local and surrounding seismic sources that could contribute to the seismic hazard of the region. The earthquake catalogue contained events reported in different magnitude scales, including surface wave magnitude (M_s), body wave magnitude (M_b), and moment magnitude (M_w). As inconsistent magnitude representation can hinder reliable seismic hazard assessment, a homogenization procedure was carried out. Accordingly, all

earthquake magnitudes were converted to a uniform Mw scale using the empirical correlations proposed by Sitharam and Sil (2014) for Mokokchung district.

Table 4.9: Empirical Correlations for Magnitude Conversion to Mw (after Sitharam & Sil, 2014)

$M_w = 0.86m_b + 1.034$	3.1
$M_w = 0.673M_L + 1.730$	3.2
$M_w = 0.625M_s + 2.350$	3.3

Based on the compiled seismotectonic database for Mokokchung District from 1980-2024, a total of 356 earthquake events were recorded. Of these, 6 events (approximately 1.55%) registered at 0 Mw, while 19 events (4.92%) fell within the 3 Mw range indicating low intensity seismic activity. The majority of events fell within the 4 Mw category, representing frequent micro to light seismic events. Additionally 53 earthquakes (comprising 13.43% of the total events) registered at magnitudes greater than 5 Mw, highlighting periodic discharge of substantial tectonic energy within localized segments of Mokokchung's active seismic framework. The seismotectonic map of Mokokchung (4.11) shows major geological formations, structural elements, and the distribution of past earthquake epicenters with magnitudes. The map highlights the tectonically active zones where seismicity is concentrated along fault and lineament systems. This finding aligns with wider geo-scientific evidence suggesting that lineaments identified through remote sensing often coincide with regions of high seismic activity as they reflect inherent structural weaknesses.

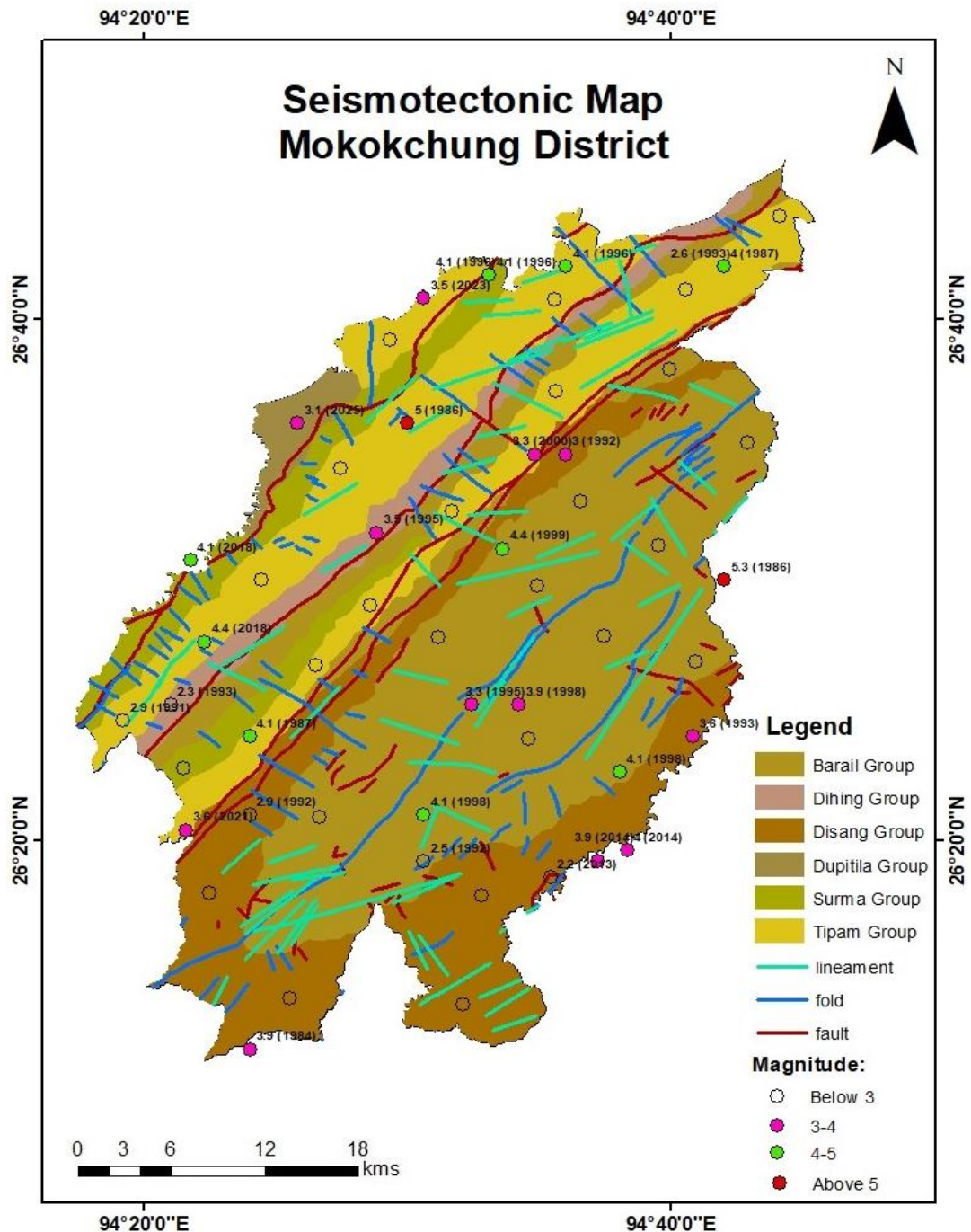


Figure 4.11: Seismotectonic Map of Mokokchung District.

The seismotectonic map of Mokokchung shows a complex relation between geological structures and seismicity, wherein faults and lineaments serve as important zones of structural weakness accelerating stress accumulation and release during earthquakes. This finding aligns with wider geoscientific evidence suggesting that lineaments identified through remote sensing coincide with regions of increased

seismic activity, as they reflect inherent structural weaknesses (Ganesha Raj & Nijagunappa, 2017). The clustering of epicenters along these features, especially with magnitudes ranging from <3 to >5 (Figure 4.11) indicates their role as active seismogenic zones suggesting continuous tectonic deformations likely caused by the convergence of the Indian Plate and the Indo-Burman ranges. The different lithology units including the Barail, Disang and Tipam groups distributed across the study area depicts increased seismicity indicating the influence of lithology on distribution of earthquake events in the study area. The spatial distribution of earthquake magnitudes as shown in the map is characterized by frequent lower magnitude events and appear to be clustering around the structurally weak zones, whereas less frequent moderate to higher magnitude events are concentrated along the key fault lines corresponding with typical patterns of strain release in convergent tectonic settings and shows areas of high seismic hazard events.

4.3.2. Micro-Earthquake Hazard Zonation

For Micro-Earthquake hazard zonation in Mokokchung district, the process of assigning weights and susceptibility rankings to major seismic hazard indicators was structured systemically using a combination of the Analytical Hierarchy Process (AHP) and empirical geological assessment, and integrated within the Scalogram Modelling Approach (SMA) of Cruz (1992) due to its relevance and effectiveness in multi-criteria seismic analysis. Seven principal factors including slope, geology, geological features, lineament density, geomorphology, earthquake density and past earthquake magnitude were considered based on their established relevance to earthquake hazard in the study area. To apply these variables effectively, each was subdivided into four sub factors or susceptibility classes ranging from very low to very high grounded in region specific geological and geomorphological characteristics. Through the AHP framework, pair-wise comparisons were conducted to ensure the relative influence on each factor on seismic risk. For each spatial unit within the district, the relevant class for all seven factors was aggregated according to the following formula:

$$MEHI = X_1 (An) + X_2 (An) + X_3 (An) + X_4 (An) + X_5 (An) + X_6 (An) + X_7 (An)$$

Here, MEHI refers to the Micro Earthquake Hazard Index. The variable ranging from X_1 to X_7 represents the contributing factors: slope, geology, geological features, lineament density, geomorphology, earthquake density and past earthquake magnitude. The value A_n represents the total weight obtained from the sub factor classes (A1, A2, A3 and A4) associated with each parameter, where the combined weight (e.g. $1+2+3+4=10$) is applied (Table 4.10).

Table 4.10: Weighted Classification Scheme of Seismic Hazard parameters for Micro Earthquake hazard Index (MEHI)

Major Factors (Xi)	Sub-Factors (Ai)	Specifications	Weights	Susceptibility
X1 Slope	A1	0-15° (gentle valley floors, floodplains)	1	Very Low
	A2	15-30°(moderate slopes, foothills)	2	Low
	A3	30-45°(steep slopes)	3	High
	A4	>45°(very steep, escarpments and unstable hills)	4	Very High
X2 Geology	A1	Fluvial sandstones, consolidated	1	Low
	A2	Sandstones, more consolidated	2	Moderate
	A3	Shales splintery, unstable	3	High
	A4	soft sediments, high seismic amplifications	4	Very High
X3 Geological Features	A1	No structural features	1	Low
	A2	Minor cracks/joints	2	Moderate
	A3	Secondary faults/fractures	3	High
	A4	Major thrusts/faults	4	Very High
X4 Lineament Density	A1	<2 km/km ² (sparse)	1	Low
	A2	2–3 km/km ² (moderate)	2	Moderate
	A3	3–4 km/km ² (dense)	3	High
	A4	>4 km/km ² (very dense, tectonically active)	4	Very High
X5 Geomorphology	A1	Denudational hills (resistant ridges, more stable)	1	Low
	A2	Structural hills (moderately stable)	2	Moderate
	A3	Dissected hills & gullies (erosion-prone)	3	High
	A4	Floodplains/valleys (unconsolidated deposits)	4	Very High

Major Factors (Xi)	Sub-Factors (Ai)	Specifications	Weights	Susceptibility
X6 Earthquake Density	A1	Seismically quiet zones (0–1 event)	1	Low
	A2	Low clusters (1–5 events)	2	Moderate
	A3	Moderate clusters (5–10 events)	3	High
	A4	High cluster zones (>10 events)	4	Very High
X7 Past Earthquake Magnitude	A1	<3	1	Low
	A2	3-4	2	Moderate
	A3	4-5	3	High
	A4	>5	4	Very High

Table 4.11: Site characteristics of seismic hazard zones of Mokokchung district.

Seismic Hazard Zones	Area		Site Characteristics
	km ²	%	
Low	629.85	39	stable geo-environment, lineament density of less than 0.18 km/ km ² , gentle to moderate slopes
Moderate	387.6	24	600-900m elevation, high level river terraces, moderately dissected hills. Several parts of settlements
High	290.7	18	High elevation and steep slopes. Several lineaments, fractured zones and fault planes traversing the region
Very High	306.85	19	Geologically very unstable, steep slopes unconsolidated materials. Vegetation is scarce, varied anthropogenic activities
Total Area	1615	100	All of the above

The study area has been classified into four distinct earthquake hazard zones based on the Micro Earthquake Hazard Index (MEHI). These zones range from low to very high hazard, reflecting the spatial variability of seismic risk within Mokokchung district (Figure 4.12).

Low hazard zone: It includes areas that experience relatively few seismic events, usually 1-4 events per 10km². The geo-environment is generally stable, with low lineament density (less than 0.8km/km²). The terrain is mostly gentle to moderately sloping, with slope angles not exceeding 17°, and consists mainly of low dissected hills and piedmont areas (Table 4.11). Geologically, it is made up of fine grained

sandstones, carbonaceous shales, siltstones, and coal seams belonging to the Barail and Disang formations. Although these lithological units show relatively low resistance to seismic stresses, the overall geomorphic stability reduces the likelihood of major seismic impacts. This zone covers about 39% (629.85 km²) of the district's total area.

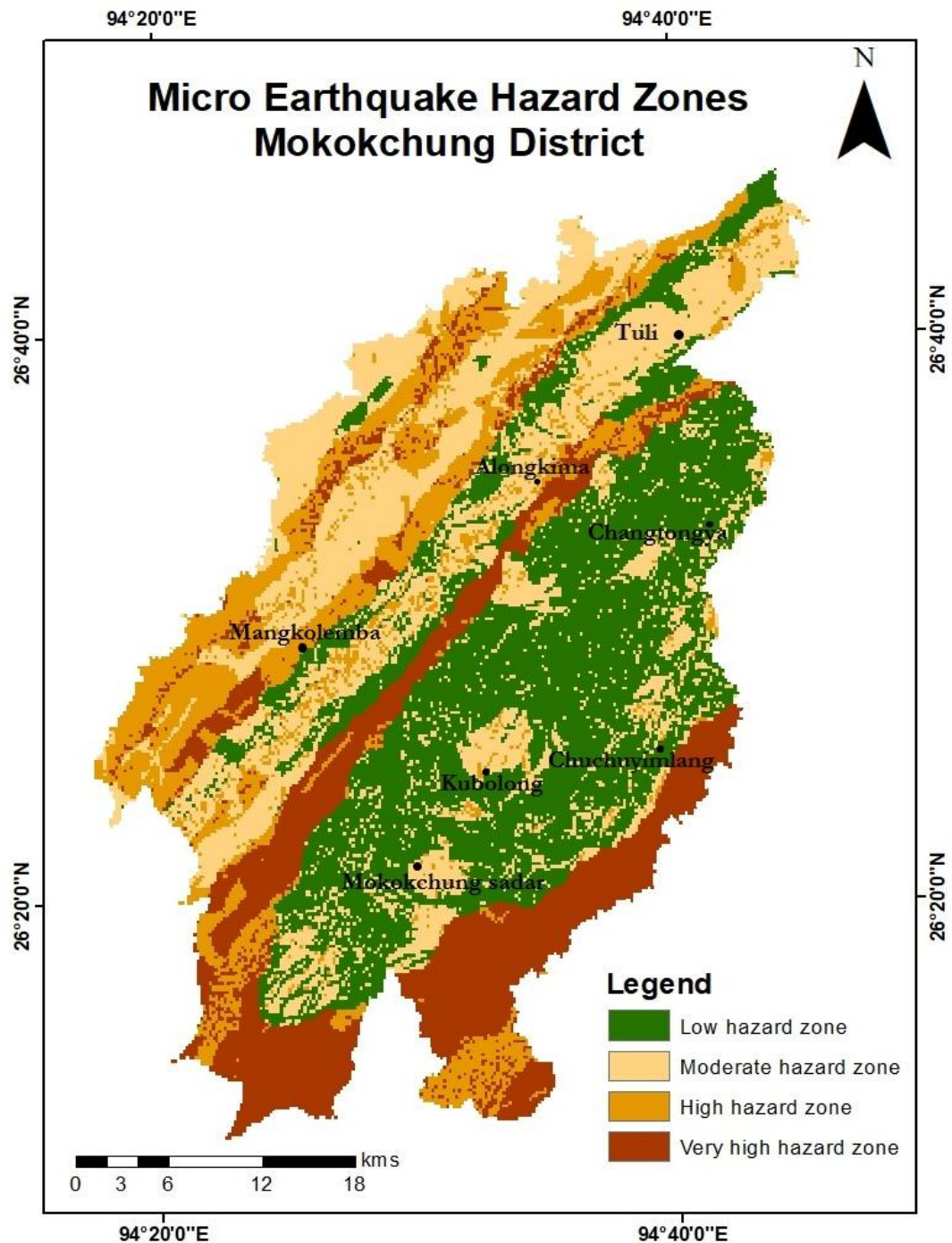


Figure 4.12: Micro Earthquake hazard zones of Mokokchung District.

Moderate hazard zone: It includes areas that experience 3-8 seismic events per 10km², representing transitional conditions between stable and unstable areas. Lineament density ranges from 0.18 to 0.37km/km² and slope gradients varying from 18° and 24°. The landscape is dominated by structural mid level hills developed in Disang and Tipam formations, comprising sandstones, silty shales, grits, and argillaceous shale units. It occurs mostly in areas with 600-900m elevation, high level river terraces, moderately dissected hills (Table 4.11). The presence of several faults and folds further increases local stress, making these areas moderately vulnerable to earthquakes. This zone covers approximately 24% (387.6 km²) of the district's total area.

High hazard zone: It includes areas that experience 8-11 seismic events per 10km² and show clear signs of structural stress. These regions have dense lineaments (0.37 and 0.55 km/km²) and steep slopes from 25° to 30°. The terrain consists mainly of structurally controlled and highly dissected moderate to high hills (Table 4.11) formed of weaker sandstones and shales of the Disang and Tipam formations. Active fault systems trending NE-SW and NW-SE further increase instability in these areas. This zone covers approximately 18% (290.7 km²) of the district's total area.

Very high hazard zone: It includes areas with more than 12 seismic events per 10km². These regions lie along major faults, thrust zones, and areas of high lineament intersection (0.55-0.92km/km²). Slopes in this zone mostly exceed 34° and the terrain is characterized by deeply dissected high hills and escarpments comprising mainly of massive Tipam and Disang sandstones that have been structurally weakened by repeated folding and faulting (Table 4.11). The presence of recorded earthquake epicenters confirms the high tectonic activity in this zone. This zone covers approximately 19% (306.85km²) of the district's total area.

4.4. Soil Erosion Hazard in Mokokchung District

Soil erosion is a fundamental geomorphological process that shapes landscapes over geological time scales through the detachment, transport, and deposition of soil, regolith, and associated organic matter by agents such as rainfall, surface runoff, wind, ice, temperature fluctuations, and gravity (Mitiku et al., 2006). While natural erosion contributes to long-term landform stability, its acceleration due to climatic variability and anthropogenic disturbance transforms it into a significant environmental hazard (Demangeot, 2002). Globally, soil erosion is considered one of the most pressing environmental challenges, with Asia recording some of the highest erosion rates upto 74 tons per acre per year ($SE = 74 \text{ t/ac/year}$) in certain regions (Pimentel et al., 1995).

In many mountain regions, intense rainfall events combined with rapid surface runoff over sparsely vegetated or exposed soils significantly accelerate erosion processes, resulting in widespread land degradation (Ristić et al., 2012; Ashiagbor et al., 2013; Tamene & Vlek, 2008). Such processes lead to the removal of fertile topsoil, the exposure of less productive subsoil layers, and increased sediment delivery to rivers, reservoirs, and floodplains. This sedimentation reduces water storage capacity and alters natural fluvial dynamics, thereby affecting downstream hydrological systems (Kandrika, 2005). In tropical ecological zones, where rainfall intensity and frequency are particularly high, soil erosion represents one of the most pervasive forms of land degradation, with profound ecological, agricultural, and socio-economic implications (Samuel et al., 2025). Persistent soil loss weakens ecosystem resilience, lowers agricultural productivity, and disrupts hydrological regimes, ultimately threatening livelihoods and food security. Soil erosion hazard is often governed by the complex interaction of soil characteristics, slope gradients, vegetation cover, rainfall intensity and the extent of land disturbance. Erosion rates are further controlled by a combination of geophysical factors such as geology, structural lineaments, soil erodibility, slope morphology, and drainage characteristics, alongside hydro-meteorological influences including rainfall, runoff, evaporation, and surface infiltration processes. Human induced pressures play a crucial role in intensifying erosion hazards. Changes in land use, inappropriate agricultural practices,

deforestation, soil disturbance, and the absence of effective conservation measures substantially increase erosion rates beyond natural thresholds (Abdo & Salloum 2017; Sharma and Singh 2017; Rawat 2003, 2011, 2012, 2017). Soil erosion can be broadly classified into two categories: geological (natural) erosion and accelerated erosion. Geological erosion is a slow and continuous process that occurs under undisturbed natural conditions and represents a fundamental component of soil formation. Operating over long geological timescales at relatively low rates, it involves the gradual weathering of parent rock material and the development of soil profiles, independent of human influence. These natural erosion rates are essential for the creation, renewal, and long term maintenance of soils. In contrast, accelerated soil erosion occurs when the rate of soil loss exceeds the natural geological norm due to environmental disturbances. Although extreme natural events may temporarily intensify erosion, human activities remain the most persistent and influential drivers of accelerated soil erosion in most landscape. Anthropogenic causes include deforestation, slash and burn agriculture, intensive tillage, uncontrolled grazing, and biomass burning (Blanco & Lal, 2008). The impacts of accelerated soil erosion are both on-site and off-site. On-site effects include the removal of fertile topsoil, reduction in soil depth, and depletion of soil organic matter, leading to declining agricultural productivity and weakened ecosystem resilience (Morgan et al., 1984; Blaikie & Brookfield, 2015). Off-site consequences involve sedimentation of rivers and reservoirs, siltation of irrigation channels, and deterioration of water quality (Vanacker et al., 2003; Navas et al., 2004). These processes disrupt hydrological regimes, increase the risk of flooding, damage infrastructure, and contribute to long-term ecological degradation.

Mokokchung district of Nagaland, located in the northeastern region of India, is characterized by a rugged, and highly dissected terrain with steep slopes and fragile geological formations, primarily composed of weathered sedimentary and meta-sedimentary rocks. The district's geomorphological setting, combined with a humid subtropical climate and high annual rainfall, makes the landscape highly vulnerable to soil erosion. In many parts of the district, unregulated land-use practices, especially traditional shifting cultivation have intensified slope instability and surface runoff.

When carried out without adequate fallow periods or soil conservation measures, these practices accelerate soil fertility loss, reduce vegetative cover, and fragment natural habitats.

The ecological consequences of these changes are closely linked with hydrological impacts. Seasonal water scarcity, marked by the drying of springs and reduced base flow in streams during dry months, contrasts sharply with the occurrence of flash floods and severe surface runoff during the monsoon season. Over time, these interacting processes have resulted in widespread land degradation, declining agricultural productivity, and shifts in livelihood strategies, sometimes leading to migration from rural areas. Such environmental pressures affect not only the district's biodiversity but also the socio-economic well-being of its population.

4.4.1. Methodology

Given the above mentioned concerns, there is a need to identify, map and assess erosion prone zones in Mokokchung district to support effective intervention and land management strategies. Accordingly, the present study applies the Revised Universal Soil Loss Equation (RUSLE) integrated with Geographic Information System (GIS) techniques to quantify and spatially analyze soil erosion risk across the district. By doing so, it aims to provide a scientific and spatially explicit basis for prioritizing soil conservation measures and promoting sustainable land-use planning.

The soil erosion study used a combination of Survey of India (SOI) topographical sheets (Nos. 83J/2, J/3, J/6, J/7, J/9, J/10, J/11, J/14, and J/15) at a mapping scale of 1:50,000 as the primary base for delineating drainage patterns, settlements and major physiographic features. Satellite datasets included USGC Landsat Imagery (30m spatial resolution) for LULC classification and NDVI based vegetation analysis, supported by high resolution Google Earth images. Terrain parameters required for soil erosion assessment such as slope gradient, aspect, relief, flow accumulation and watershed boundaries were derived from the NASA SRTM Digital Elevation Model (DEM) at 30 m resolution. Rainfall data spanning for a period of 20 years (2001-2022) were sourced from CHRS and supplemented with

meteorological observation from IMD stations in and around the study area. Soil information was obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS) providing necessary detailed soil datasets for further analysis.

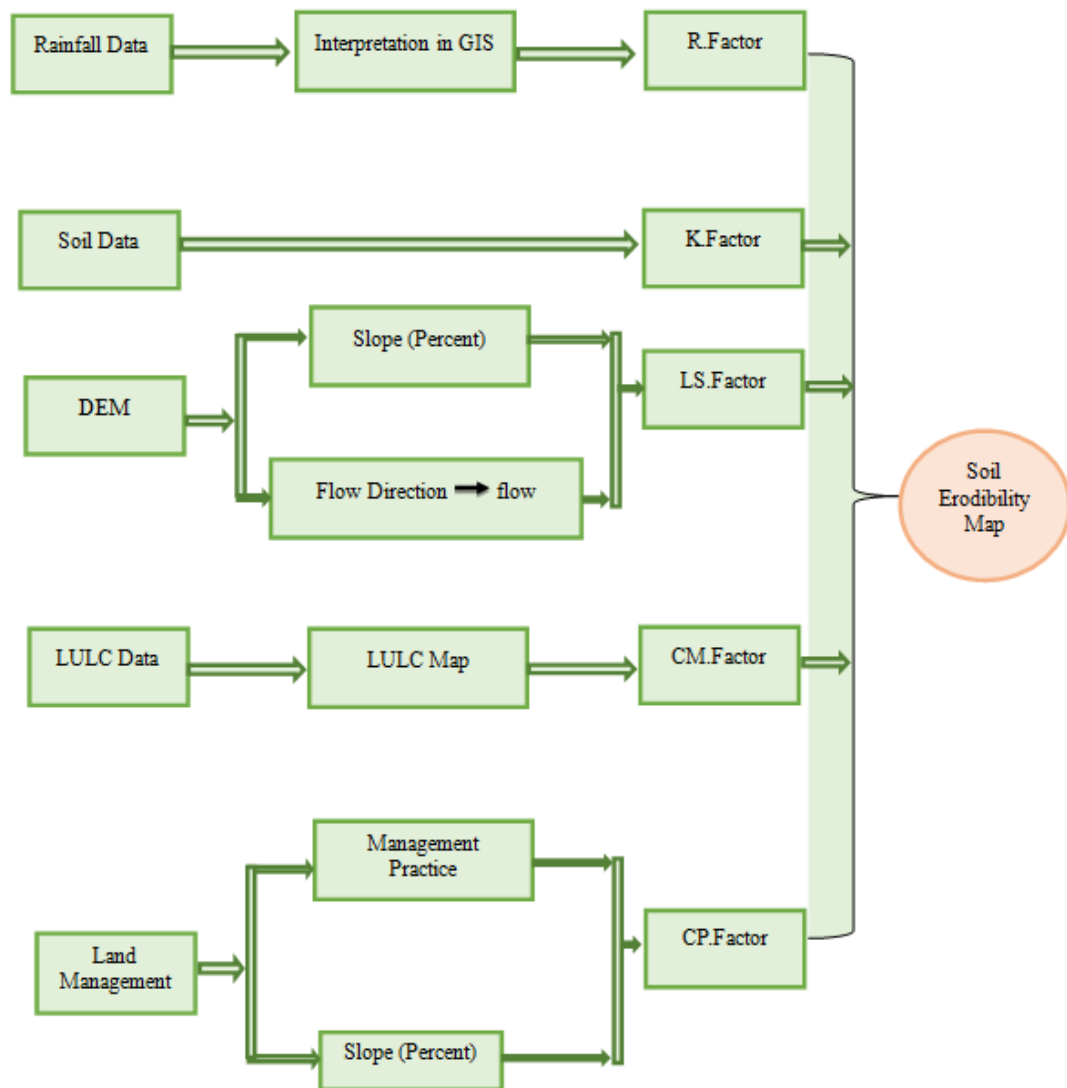


Figure 4.13: Methodology for Revised Universal Soil Erosion Equation (RUSLE) modeling for Mokokchung District.

4.4.2. Revised Universal Soil Erosion Equation (RUSLE)

Several soil erosion models with differing complexities have been developed to estimate erosion rates under different environmental conditions. Among these, the Universal Soil Loss Equation (USLE), originally proposed by Wischmeier and Smith

(1965) and later revised as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) is one of the most widely applied empirical models for assessing sheet and rill erosion. Although initially developed for croplands and gently sloping terrains, RUSLE has retained its relevance through subsequent modifications and adaptations. Variants such as the Modified Universal Soil Loss Equation (MUSLE) (Wischmeier & Smith, 1978; Van Remortel et al., 2001; Lee & Lee, 2006) have expanded its applicability to a broader range of environmental settings, and the model continues to be extensively used in soil erosion assessment studies worldwide. RUSLE offers varied advantages, including its flexibility, relative simplicity, cost and time effectiveness, and suitability for application in data scarce regions. However, the model also has limitations, such as constraints in spatial coverage, reduced reliability under certain conditions, and the potential overestimation of the soil erodibility factor (K). Despite these limitations, its robustness and adaptability make it a practical tool for regional scale erosion assessment. The integration of RUSLE with remote sensing, Geospatial Science and Technology, and Geographic Information Systems has enhanced its accuracy and spatial applicability (Fernandez et al., 2003; Gitas et al., 2009; Xu et al., 2009; Ganesri & Ramesh, 2016). A critical input for erosion modeling is the Digital Elevation Model (DEM), which can be derived from stereoscopic optical or microwave (SAR) remote sensing data (Kim, 2006). The cell by cell computational framework of RUSLE enables the spatial estimation of soil loss across large areas, while GIS provides an effective platform for integrating multiple variables, analyzing erosion dynamics, and delineating soil erosion probability zones (Shinde et al., 2010). This study therefore aims to develop a methodology integrating Remote Sensing, GIS, and RUSLE to estimate catchment scale soil erosion, assess the impacts of land use land cover change on erosion, and delineate erosion prone zones through GIS based overlay analysis.

It is a widely used empirical model for estimating soil erosion, valued for its simplicity and adaptability at different spatial scales. By incorporating rainfall, soil, topography, land cover, and conservation practices, RUSLE provides a quantitative framework for assessing annual soil loss. With the aid of GIS and remote sensing, factors such as slope, aspect, and land use/land cover (LULC) derived from digital

elevation models (DEMs) can be effectively integrated, making RUSLE a practical tool for erosion hazard mapping. The principal model for RUSLE model is as:

$$A = R \times K \times LS \times C \times P$$

Where A= Soil Loss

R= Rainfall Erosivity Factor

K= Soil Erodibility Factor

LS= Topographic Factor

C= Cover Management Factor

P= Conservation Practice Factor

4.4.2.1. Rainfall Erosivity Factor: The rainfall erosivity factor (R) represents the influence of rainfall on soil erosion by accounting for both the amount of precipitation and its intensity. It reflects the kinetic energy of raindrop impact as well as the runoff generated during storm events. Accurate estimation of R generally requires continuous precipitation data, as storm duration, total rainfall, and peak intensity are the primary drivers of erosive potential (Wischmeier & Smith, 1978). Mean annual rainfall data for 20 years was used to estimate R factor following Morgan et al. (1984):

$$R = 38.5 + 0.35P$$

where R = rainfall erosivity factor, P = mean annual rain fall in mm.

The spatial distribution of average annual erosivity in Mokokchung for the period (2001-2022) ranges from approximately 425 to 476 MJ mm/ha/h/year across the study area (Figure 4.14). The northern and northwestern parts of the district exhibit comparatively higher RE values. These higher values influenced by increased rainfall intensity along with topographic features that enhance surface runoff. The southern and southeastern zones exhibit lower erosivity values indicating reduced rainfall

intensity and potentially higher infiltration capacity. The central zones exhibit moderate erosivity levels forming a transitional zone between areas of high and low erosivity. The spatial pattern of rainfall erosivity across Mokokchung exhibits a gradual north-west to south-east variation delineating zones with differing susceptibility to rainfall driven erosion.

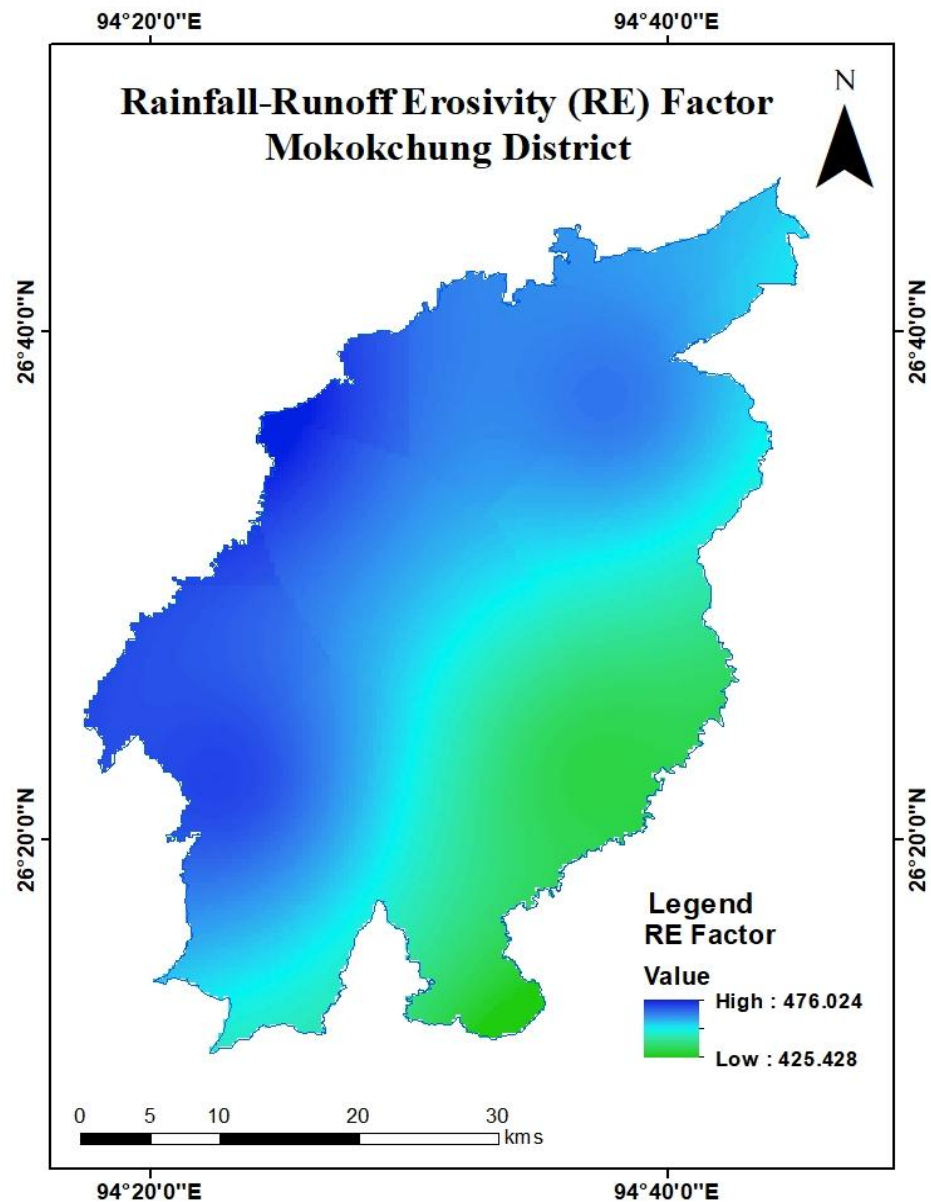


Figure 4.14: Rainfall Runoff Erosivity Map of Mokokchung District.

4.4.2.2. Soil Erodibility Factor: The soil erodibility factor (K) reflects the inherent susceptibility of soil to erosion based on its physical properties, particularly texture, structure, organic matter content, and permeability (Renard et al., 1997). It is defined as the mean annual rate of soil loss per unit of rainfall erosivity under standard conditions of bare, recently tilled soil on a 22.6 m long plot with a 9% slope and no conservation practices (Morgan, 2005). Essentially, the K factor indicates the ease with which soil particles detach and are transported by rainfall and runoff, and is commonly estimated from soil texture and related properties.

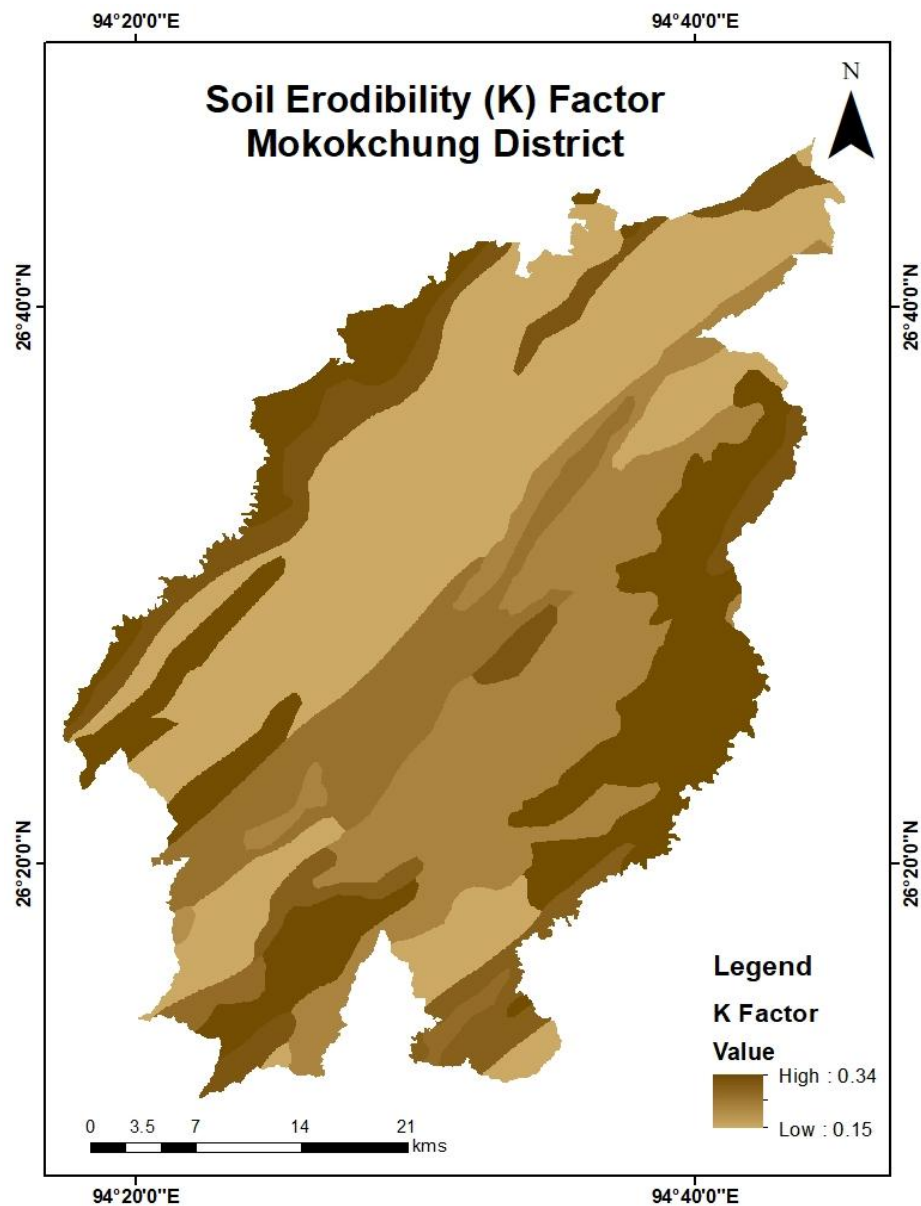


Figure 4.15: Soil Erodibility Map of Mokokchung District.

The soil erodibility factor reflects the inherent susceptibility of soil particles to detachment and transport across Mokokchung district from 0.15 to 0.34 (Figure 4.15). The central and northeastern parts of the district exhibit higher K values which suggests that soils are more prone to erosion due to characteristics such as fine particle size, reduced structural stability and potentially lower organic matter. Comparatively, the southern and western zones exhibit lower erodibility values. Soils in these zones appear to be resistant to detachment, likely owing to coarser texture and greater structural and aggregate stability. This spatial variation reflects notable differences in soil texture and pedogenesis across the district.

4.4.2.3. Topographic Factor: The topographic factor (LS) in RUSLE represents the combined influence of slope length (L) and slope steepness (S) on soil erosion. Derived from DEMs, this factor captures the manner in which surface runoff accumulates and accelerates downslope, thereby increasing the erosive power acting on soil particles (Morgan et al., 1992). The LS factor represents the ratio of soil loss from a standard USLE unit plot measuring 22.6 m in length with a 9% slope (Wischmeier & Smith, 1978). While the original USLE equations were primarily developed for unit plots and field scale applications, RUSLE extended this concept to one dimensional hillslopes and introduced modified formulations to better represent slopes steeper than 9 per cent (Renard et al., 1997; Benavidez et al., 2018). Subsequent methodological advances have further improved the estimation of the LS factor in complex terrains. In particular, the approach proposed by Desmet and Govers (1996) allows LS to be calculated using flow accumulation and contributing area, making it well suited for heterogenous and rugged landscapes. This development has significantly enhanced the ability of RUSLE to model spatial variations in soil erosion under diverse topographic conditions. The LS factor was derived from DEM based flow accumulation layers generated in ArcGIS using the equation proposed by Moore and Burch (1986) to quantify the topographic influence on soil erosion.

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

The slope length and steepness varies between 0 and 20.481 across Mokokchung district as shown in Figure 4.16. It demonstrates a predominance of low to moderate values throughout most of the area, indicating gentle to moderately sloping terrain. Such areas are likely to experience comparatively lower rate of surface runoff velocity and soil displacement. In contrast, discrete high elevation and steep slope area display noticeably higher LS values where concentrated runoff and gravity significantly enhance erosion potential.

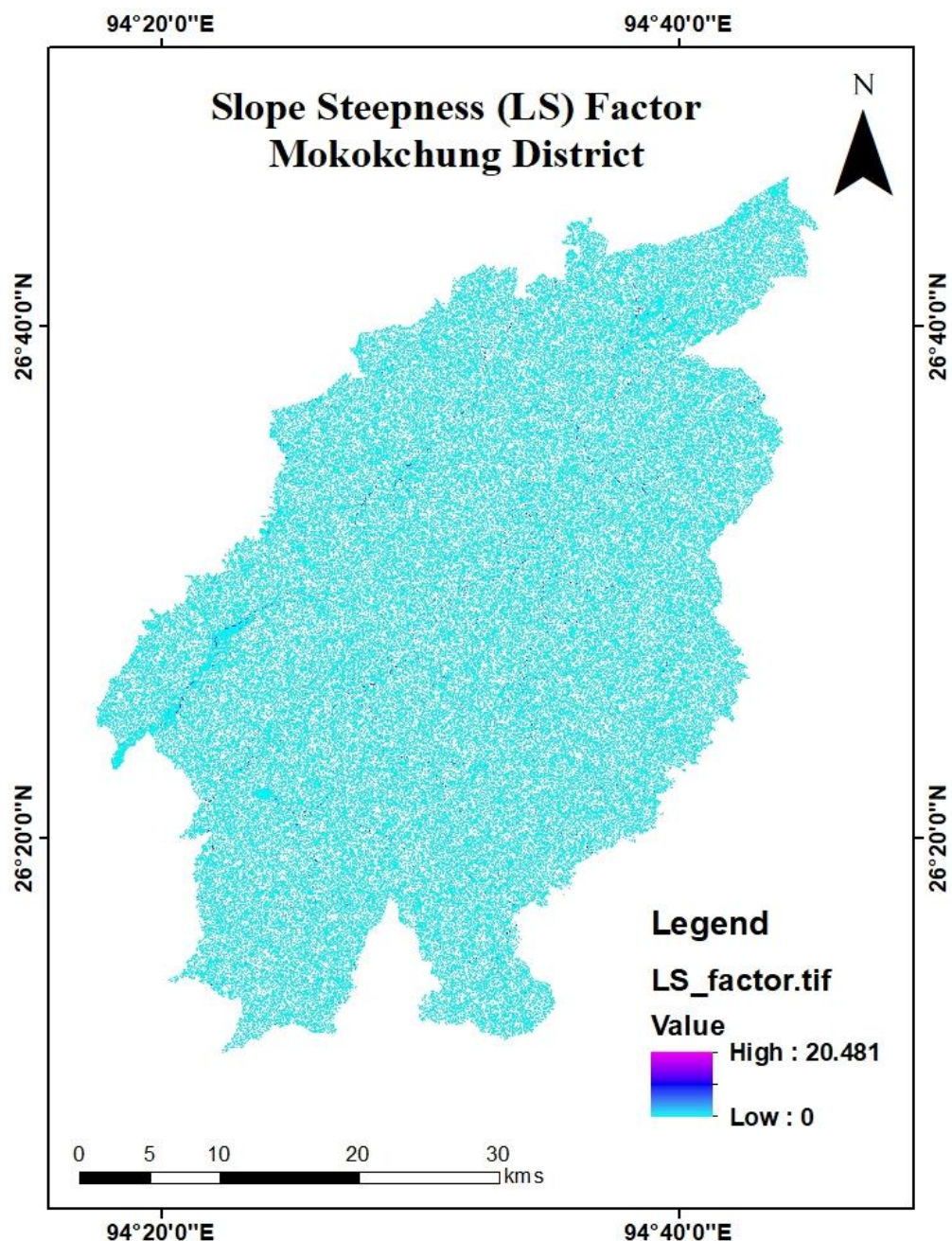


Figure 4.16: Slope Steepness Factor Map of Mokokchung District.

4.4.2.4. Cover Management Factor: The cover management factor (C) quantifies the effect of vegetation, cropping, and land management practices on soil erosion. It is defined as the ratio of soil loss from land under specific cover and management conditions to that from continuously bare fallow (Wischmeier & Smith, 1978). Being highly spatio-temporally variable, the C factor reflects seasonal changes in plant growth and rainfall dynamics (Nearing et al., 2004; Chalise et al., 2019). In practice, it is commonly derived from land use and crop management information, often obtained through land use/land cover (LULC) maps of the study area. The Normalized Difference Vegetation Index (NDVI) was used in this study to assess vegetation conditions across the area. NDVI is a widely recognized spectral index derived from satellite imagery that indicates the density and vigor of vegetation cover. It is computed using reflectance values from the near infrared (NIR) and red (R) bands as:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where, NIR= reflectance in the near-infrared band

R = reflectance in the red band

NDVI = Normalized Difference Vegetation Index

To derive the cover management factor (C factor), which represents the effect of vegetation cover on soil erosion, the approach suggested by Durigon et al. (2014) was applied. The C factor was estimated from NDVI values using the following transformation:

$$C = \frac{(-NDVI + 1)}{2}$$

The spatial distribution of Cover Management practices across Mokokchung district demonstrates noticeably variability that reflects differences in vegetation cover, crop intensity and land use practices. The values range from approximately 0.20 to 0.55, with lower values generally found in areas with dense forest and undisturbed vegetation (Figure 4.17). Comparatively, higher values occur in areas characterized by

agricultural activity, sparse vegetation, shifting cultivation patches and settlement associated land modification.

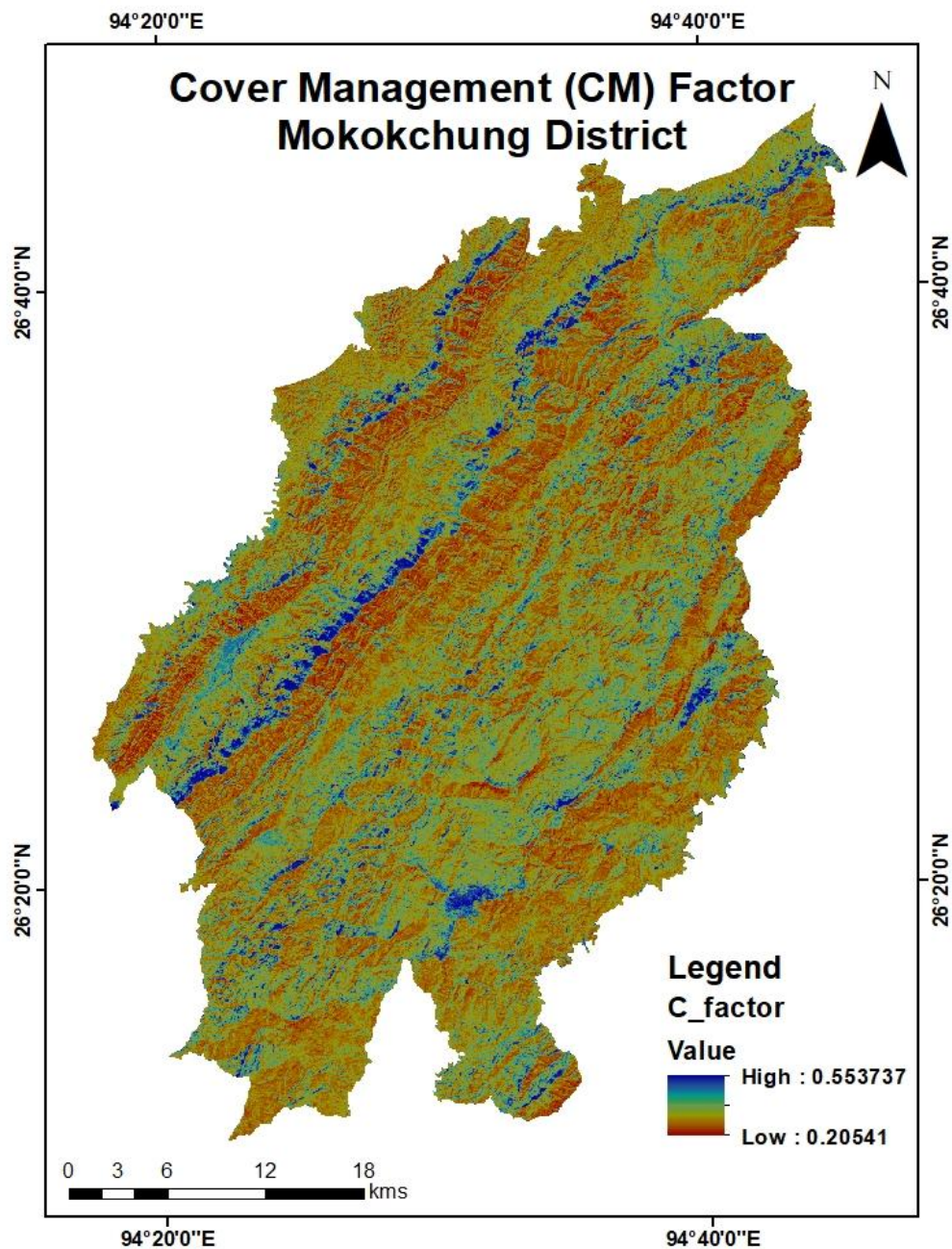


Figure 4.17: Cover Management factor Map of Mokokchung District.

4.2.2.5. Conservation Practice Factor: The conservation practice factor (P) represents the effectiveness of soil conservation measures in reducing erosion. It is defined as the ratio of soil loss from land managed with specific conservation practices such as contouring, strip cropping, or terracing, to that from land under conventional

upslope/downslope tillage without conservation measures (Renard et al., 1997). By altering runoff pathways, velocity, and concentration, these practices lower the erosive power of surface flow. Consequently, the more effective the conservation practice, the lower the P factor value (Bagherzadeh, 2014).

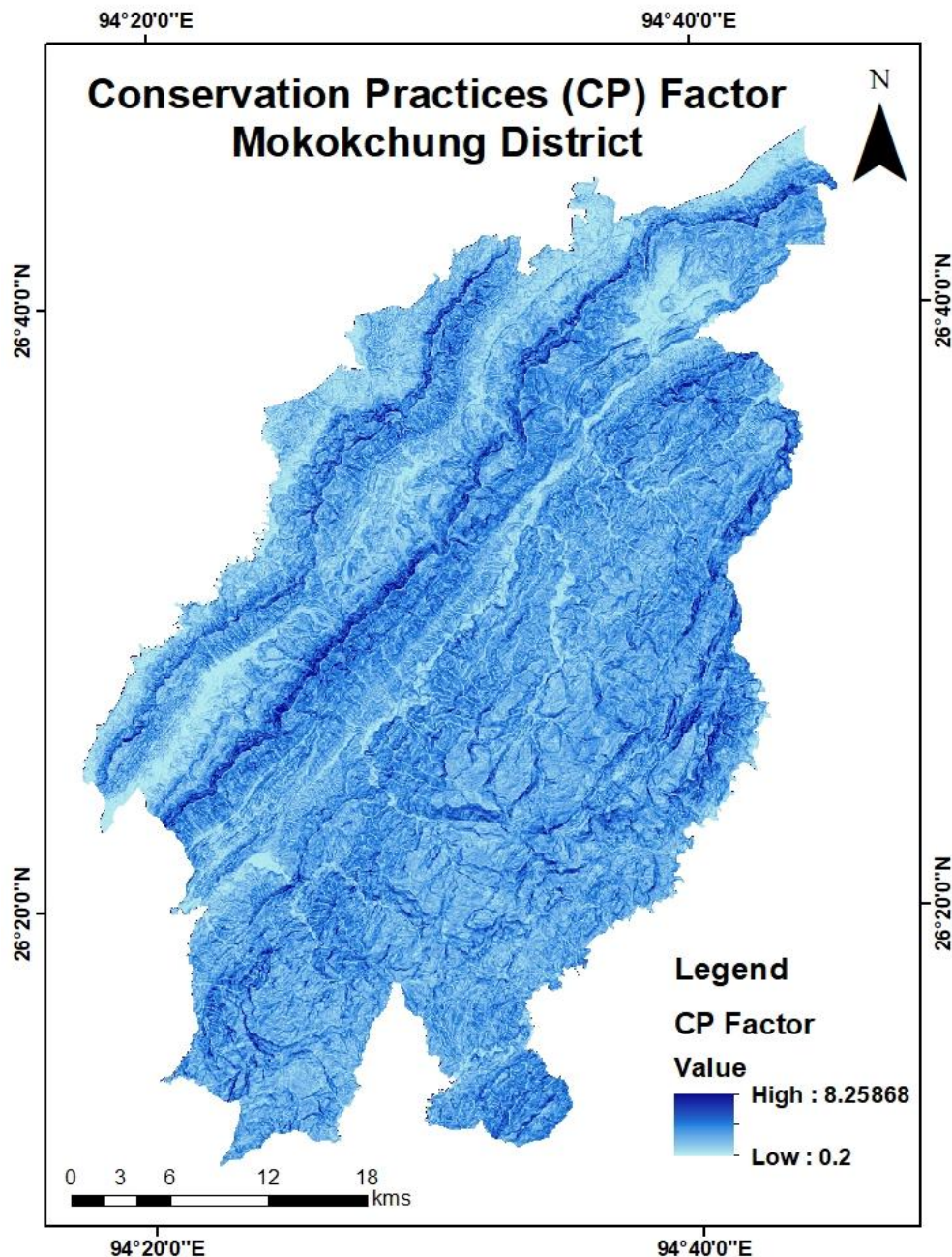


Figure 4.18: Conservation Practices factor Map of Mokokchung District.

The values of Conservation Practice range from approximately 0.20 to 8.25 (Figure 4.18), suggesting a wide gradient in land management effectiveness across the

district. Areas with lower values are more commonly found in forested regions and terrain where traditional land management practices are still maintained. Higher values occur predominantly along steep agricultural slopes, road cut areas and expanding urban areas with minimal conservation practices.

4.4.3. Soil Erosion Hazard Zonation

The soil loss estimation of Mokokchung district, carried out using RUSLE model integrated with GIS techniques illustrates a spatial variability in the distribution of erosion intensity across the terrain. The district covering an area of 1615 km², exhibits an annual soil loss with values ranging from 0-78 t/ha/year. Based on this variability, the study area has been grouped into four erodibility zones: low, moderate, high and very high which has been shown in Figure 4.19.

Low erodibility zone (<20): It is mainly found in the southern and northwestern valley regions as depicted in Figure 4.19. The soils are moderately deep, well-drained clayey soils occurring on gentle slopes and valley floors (Table 4.12). Because the soils are fairly cohesive allowing moderate water movement, soil particles are less easily washed away. As a result, these areas experience very low soil erosion and are also least affected by erosion related hazards. This zone covers approximately 14% (211 km²) of the district's total area.

Moderate erodibility zone (20-40): It can be found mainly in the central and eastern parts of the district as depicted in Figure 4.19, especially along river terraces and gently sloping landforms. The soils are mainly derived from sandstone and shale formations. While these areas are more stable than steep hill slopes, heavy rainfall, especially during the monsoon, can cause sheet erosion, small channels, and local slope failures (Table 4.12). This zone is the most extensive and covers approximately 38% (612 km²) of the district's total area.

High erodibility zone (40-60): It is mainly found in the western and northwestern hilly regions as depicted in Figure 4.19. The underlying rocks of these regions such as shale, sandstone, and phyllite, are weak and highly fractured. Combined with steep

slopes and poor soil structure, these conditions make the area highly prone to erosion during intense rainfall. Field observations show frequent occurrence of landslides, gully erosion and debris flows, especially in areas disturbed by shifting cultivation, road construction, and growing settlements (Table 4.12) This zone covers approximately 28% (451 km²) of the district's total area.

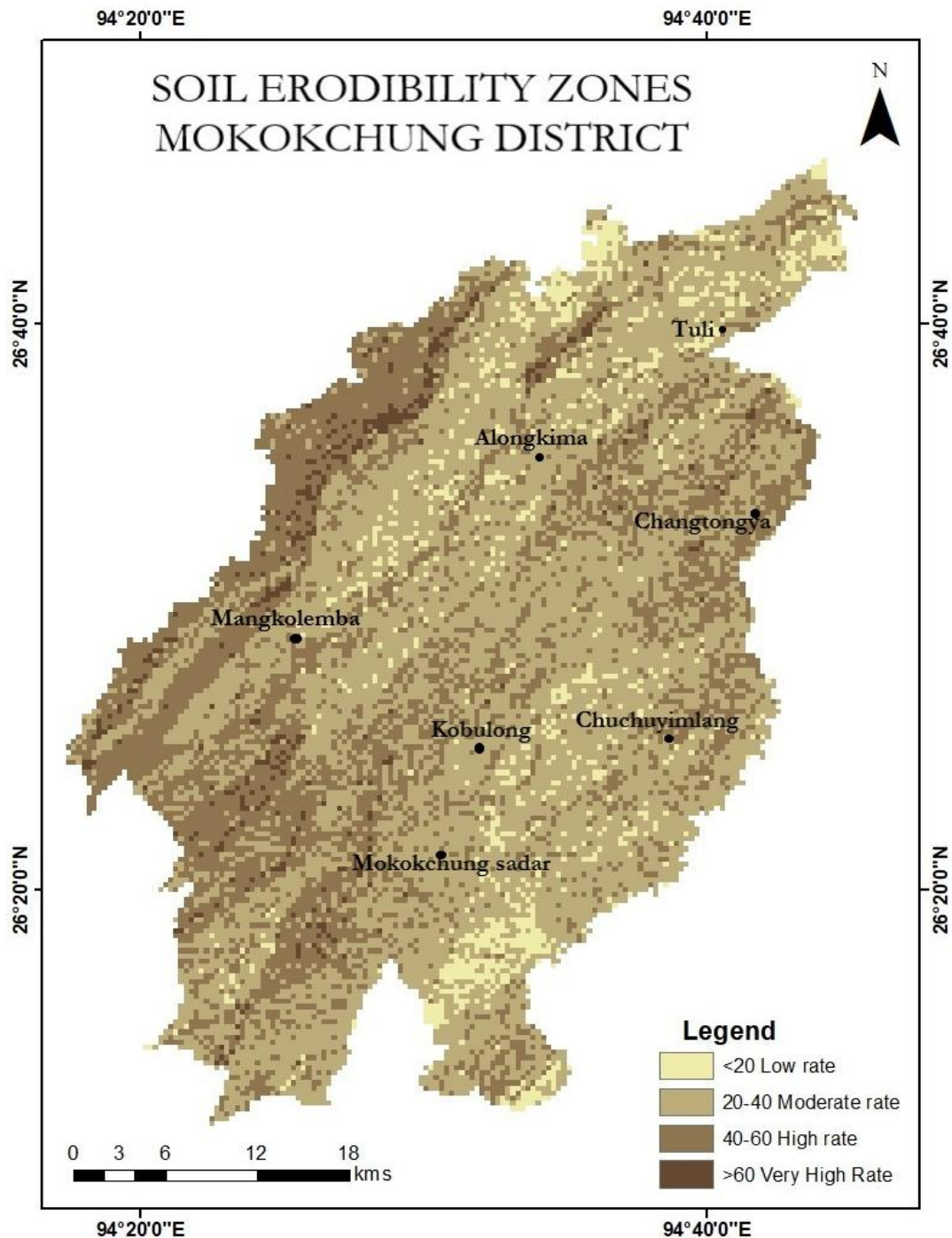


Figure 4.19: Soil erodibility zones map of Mokokchung District.

Very High erodibility zone (>60): It is mainly concentrated in the rugged northern and northwestern hill ranges as depicted in Figure 4.19. The soils are deep but excessively drained and occur on steep, unstable slopes (Table 4.12). These conditions make the area extremely vulnerable to landslides, slope failures, and mass movements. This zone covers approximately 20% (327 km²) of the district's total area which is about 20% of the total geographical area. These regions represent the most vulnerable landscapes in Mokokchung, where soil conservation and sustainable land-use practices are essential to prevent further environmental damage.

Table 4.12: Soil erodibility zonation attributes

Soil Erodibility Zones	Area		Attributes of hazard zones
	km ²	%	
Low Rate (<20)	211	14	southern and northwestern valleys, exhibits moderately deep, well drained clayey soils on gently sloping ridges valley, cohesion and moderate permeability reduce detachment
Moderate Rate(20-40)	612	38	central and eastern regions, typically associated with soils derived from inter-bedded sandstone and shale formations, susceptible to high intensity rainfall, rill erosion, sheet wash and localized slope failures, seasonal monsoon storms often accelerate erosion in these moderate zones
High Rate(40-60)	451	28	western and north-western hilly regions, underlying geology consists of shale, sandstone and phyllite rock types, high susceptibility to fracturing, combined with steep slopes make them highly prone to detachments during heavy rainfall events, landslides, gully erosion and debris flows
Very High (>60)	327	20	rugged northern and north-western hill ranges, this zone encompasses deep, excessively drained clayey skeletal soils making the region exceptionally prone to landslides, slope failures and mass movements, most vulnerable regions of Mokokchung
Total	1612	100	All of the above

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ASSESSMENT OF VULNERABILITY, EXPOSURE AND RISK TO GEOMORPHOLOGICAL HAZARDS

Vulnerability, exposure, and risk assessments in mountainous and environmentally sensitive regions are important for understanding landscape and community resilience to geomorphological hazards. In scientific terms, vulnerability refers to how susceptible a system, population, or environment is to damage when exposed to natural hazards (Cutter, 1996; Wisner et al., 2004). It is rarely determined by a single factor; instead, it emerges from a mix of influences, including physical fragility, land-use practices, socio-economic conditions, cultural adaptations, and institutional capacity (Blackie et al., 1994). On the other hand, risk measures the likelihood of a hazard occurring along with the potential consequences, losses, or damages that result (UNISDR, 2009). In other words, hazards are part of natural processes, while risk only arises when those hazards interact with vulnerable systems or populations.

Increasingly, researchers recognize that vulnerability is not fixed. It evolves over time in response to environmental changes, population growth, economic development, and shifts in how humans interact with land (Turner et al., 2003; Birkmann, 2013). Many studies show that the interplay between natural geomorphic processes and human activities continually reshapes landscapes, turning areas that were once environmentally resilient into zones of heightened vulnerability (Glade, Anderson & Crozier, 2005). As urbanization, infrastructure expansion, and land-use changes accelerate especially in mountainous regions where hazard exposure grows while ecosystem resilience declines (Meyer et al., 2014; Pentley, 2010).

In mountainous regions like Mokokchung, natural hazards such as landslides, soil erosion, slope failure, and flash floods are quite common. These hazards mainly occur because of the region's steep slopes, active tectonic conditions, and heavy rainfall (Valdiya, 2016; Singh, 2020). Yet human activity also plays a key role due to deforestation, road and slope cutting, infrastructure development, and rising land use

pressure have all disturbed the natural balance. When these human pressures combine with natural conditions, they create a more unstable environment with higher risk. In Mokokchung, vulnerability is shaped by the complex interaction of physical geography, climate variability, land-use changes, and socio-economic factors, highlighting how closely environmental processes and human activities are linked over time.

5.1. Deforestation and Forest Cover Change

Deforestation is the permanent clearing or removal of large areas of trees and forests, and it can have far reaching environmental, social, and geomorphological consequences. The Food and Agriculture Organization (FAO, 2020) defines it as the conversion of forest land to other uses mainly agriculture, settlements, or infrastructure leading to the degradation of forest ecosystems. According to Geist and Lambin (2002), deforestation rarely stems from a single cause. Instead, it is driven by a mix of immediate pressures, such as agricultural expansion, logging, and road construction, as well as deeper factors like population growth and policy decisions.

The impacts of deforestation on the environment and landforms have long been a concern for earth scientists and hazard researchers. Vegetation plays a critical role in stabilizing slopes and controlling water flow, as roots bind soil, reduce surface runoff, and maintain slope integrity (Montgomery, 2007). When forests are removed, soils are left exposed, runoff increases, and slopes become more susceptible to failure. This in turn, raises the risk of landslides, flash floods, and gully formation. Soil erosion from deforestation also diminishes agricultural productivity and contributes to sediment related hazards (Pimentel & Kounang, 1998).

Moreover, deforestation interacts with climate variability to amplify hazard events. Forest loss disrupts natural processes like infiltration and evapotranspiration, leading to quicker runoff and more extreme hydrological responses, which can trigger flash floods, debris flows, and other sudden events (Bruijnzeel, 2004). In short, removing forest cover destabilizes landscapes and intensifies both environmental and hazard related risks. Supporting this view, Sidle et al. (2006) noted that deforested

mountain slopes experience significantly more shallow landslides than forested slopes, reinforcing the important protective role of vegetation in hazard mitigation.

The Northeastern region of India is the most extensively forested region of the country. Despite this, it has experienced a noticeable decline in forest cover over the past decade. According to India State of Forest Reports (ISFR), the region recorded a net loss of approximately 765 km² of forest between the years 2017 and 2019. Longer term trends indicate that this decline is not temporary but part of a continuing pattern of forest reduction. For example, Nagaland alone lost about 794 km² of forest cover between 2013 and 2023, representing nearly 6.1% of its total forest area (India Spend, 2025). This pattern aligns with the downward trends documented in the India State of Forest Report 2023 (FSI, 2024a). The primary factors leading to this growing deforestation rate can be linked to the increasing pressure of land use. Of all, shifting cultivation remains a significant contributor, alongside the expansion of settlements, commercial plantations, and linear infrastructure such as roads and transmission lines. All these activities together have placed sustained pressure on forest ecosystems across the region.

5.1.1. Tree Cover and Primary Forest Loss in Mokokchung District

Mokokchung District has undergone substantial deforestation over the past two decades according to data obtained from Global Forest Watch, 2024 (Figure 5.1). Between 2001 and 2024, Mokokchung district lost approximately 25.6 hectares of tree cover, accounting for nearly 19% of the total forest cover that existed in 2000. This indicates a substantial reduction in forest resources over the past two decades. More concerning, however, is the decline in humid primary forests, which represent the most ecologically valuable and carbon dense forest type in the region. Between 2002 and 2024, these primary forests decreased by about 2.34 thousand hectares (11%). This trend highlights not only the overall reduction in tree cover but also the massive depletion of primary forest ecosystems which are largely irreplaceable due to their rich biodiversity and critical ecological functions including carbon storage, soil stability, and hydrological regulation.

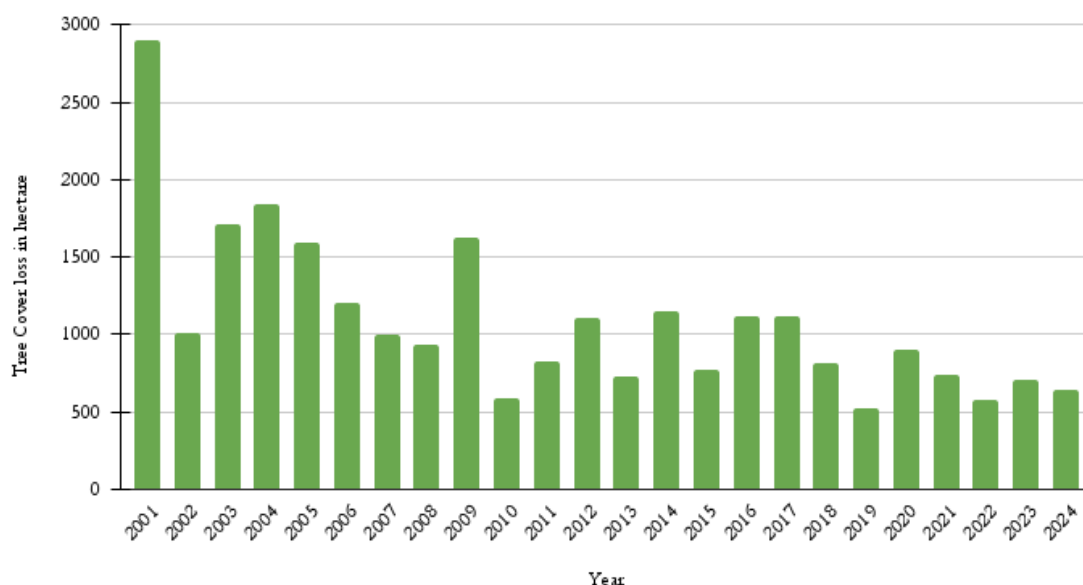


Figure 5.1: Tree Cover loss in Mokokchung District, 2001-2024
(Source: Global Forest Watch).

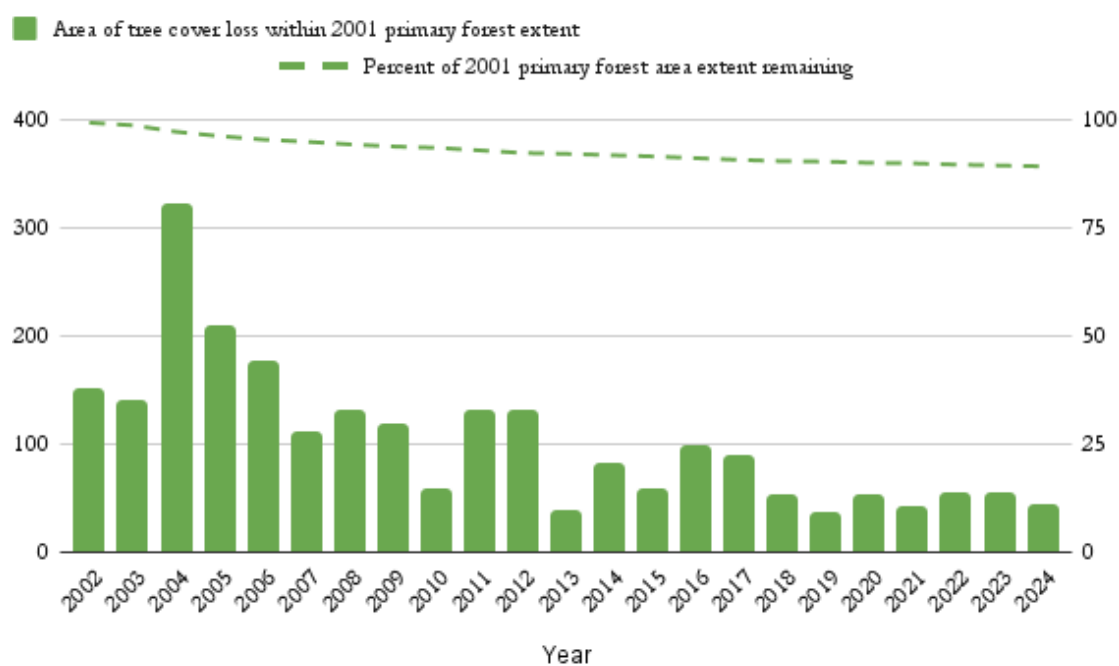


Figure 5.2: Primary Forest Loss in Mokokchung District, 2002-2024
(Source: Global Forest Watch).

The temporal trend of forest loss in Mokokchung, as shown in Figure 5.2, reveals noticeable ups and downs rather than a steady decline. Significant increase occurred in the early 2000s, especially around 2001, 2004-2006, and 2011-2015, likely linked

to intensified human activities such as logging, expansion of shifting cultivation, and infrastructure development. More recently, from 2018 to 2024, forest loss has continued but at a somewhat slower pace. While the rate of decline seems to have eased, pressures on the forests have not disappeared and continue to shape the landscape.

Overall the pattern of forest loss in Mokokchung district reflects two important dimensions of deforestation: a reduction in total forest area and the degradation of primary forest ecosystems. This means that deforestation is not just about shrinking forests but also about declining forest quality, which has long-term consequences for ecological stability and vulnerability to hazards. The fact that forest loss persists, even in recent years, underscores the urgent need for sustainable forest management and conservation strategies to protect the environment and reduce future risks.

5.1.2. Spatial Distribution of Forest Cover and tree Loss in Mokokchung District

The spatial pattern of forests in Mokokchung district shown in Figure 5.3 reveals a heterogeneous distribution of primary forests and tree cover loss areas indicating both ecological richness and vulnerability. Concentrations of intact primary forests are more evident in the northern, northwestern, and southwestern highland zones. These areas correspond to relatively rugged and less accessible terrain, where traditional land use pressures are comparatively lower. The persistence of dense primary forest cover in these parts highlights the ecological resilience of upland ecosystems that are less disturbed by intensive agriculture or settlement expansion. In contrast, widespread tree cover loss dominates the central, southern, and eastern portions of the district. These areas show extensive fragmentation, particularly along river valleys, foothills, and settlement belts, which are formerly associated with shifting cultivation (Jhum), agricultural expansion, and fuel wood extraction. The spatial distribution shows that primary forests are concentrated in the northern and western uplands, while tree cover loss is widespread in the central, southern, and eastern parts of the district. Overall, the spatial distribution demonstrates a gradient of forest integrity, with better preserved forest cores in the north and west, and significant forest depletion in the central and southern landscapes which has been shown in Figure 5.3. This pattern has direct

implications for geomorphological hazards such as soil erosion and landslides, since areas of tree cover loss coincide with steep terrain and fragile soils, thereby exacerbating vulnerability.

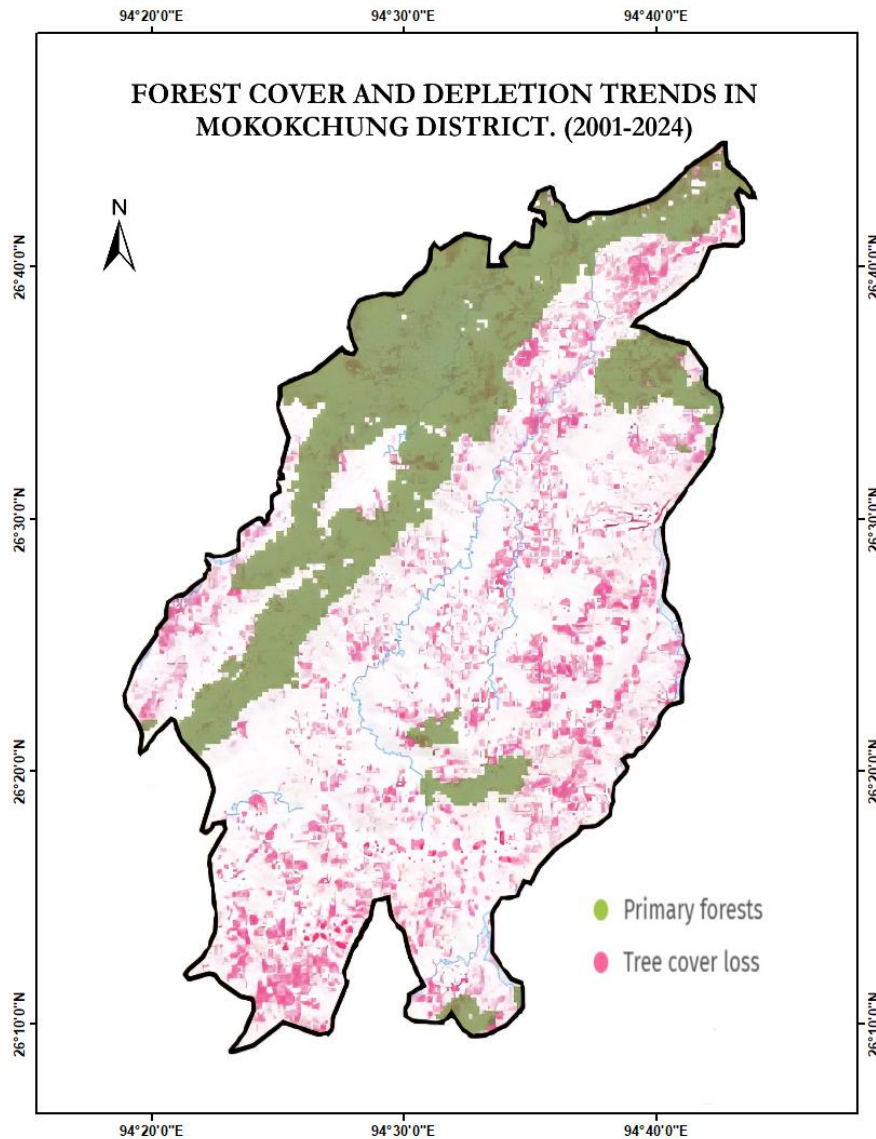


Figure 5.3: Forest Cover and Depletion Trends in Mokokchung District, 2001-2024
(Source: Global Forest Watch).

5.1.3: Drivers and Spatial Distribution of Deforestation in Mokokchung District

Figure 5.4 illustrates how forest disturbances are spread across Mokokchung, showing that deforestation results from a mix of interacting factors, each affecting different parts of the district. These observations are based on Global Forest Watch

data from 2001-2024, which track both long term and more recent patterns of forest loss and modification. The main drivers of forest disturbance in the district are linked closely to human land use as well as natural processes, and can be summarized as follows:

5.1.3.1. Permanent Deforestation Drivers

Permanent agriculture (2.3 kha): Permanent Agriculture (2.3 kha): Agriculture remains the leading cause of deforestation, especially in lower elevation valleys and gently sloping areas where terraced and irrigated cultivation is feasible. Over time, forests in these areas have been steadily replaced by permanent agricultural systems, including horticulture. The clustering of farmland around settlements indicates a gradual outward expansion pattern, driven by population growth, food production demands, and increasing pressure for land associated with settlement development.

Hard Commodities (150 ha): Although smaller in scale, the extraction of hard commodities such as stone and coal has a notable environmental impact. These activities are scattered across the district, often near areas where land-use practices are shifting toward commercial production. They tend to occur near settlements, along lower slopes, roads, and foothill areas, and in proximity to plantations, reflecting the growing orientation of rural economies toward market-driven production.

Settlements and Infrastructure expansion (220 ha): Expansion of settlements and infrastructure is a significant and growing contributor to deforestation, affecting roughly 220 hectares. These changes are concentrated in urban and semi-urban clusters, while linear development along highways, feeder roads, and transportation corridors shows how accessibility drives land conversion. Much of this expansion occurs on ridge tops, valley edges, and along transport routes where terrain is stable and civic facilities are accessible. Unlike other forms of disturbance, settlement growth is permanent, replacing natural vegetation with residential, commercial, and transport infrastructure, and introducing long-term geomorphological changes to the landscape.

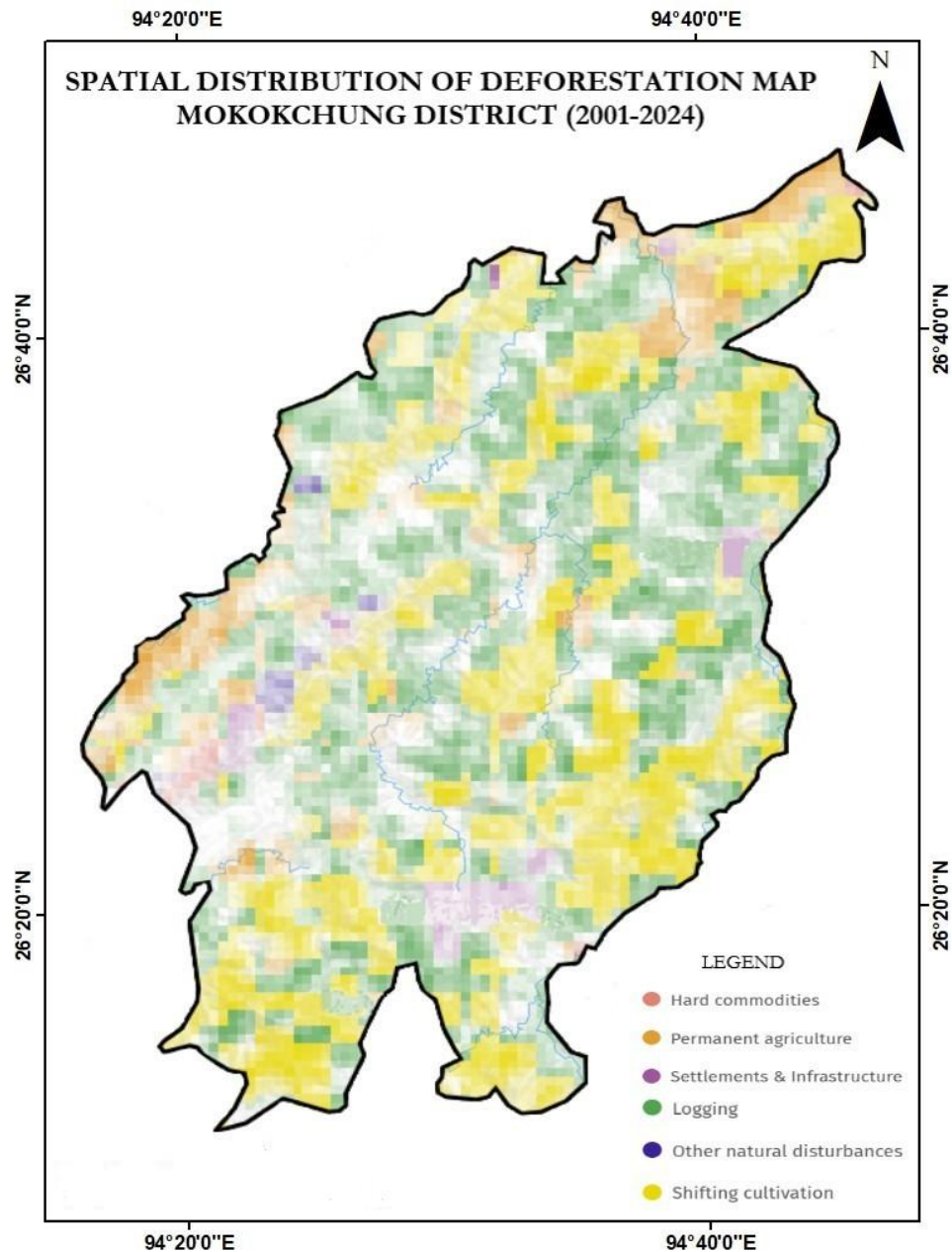


Figure 5.4: Drivers and Spatial Distribution of Deforestation in Mokokchung District, 2001-2024 (Source: Global Forest Watch).

5.1.3.2. Temporary Forest disturbances

Logging (10kha): Logging is one of the main drivers of forest disturbance in Mokokchung, particularly in the upland forest zones, rather than being concentrated near settlements. The activity is scattered across dense forest areas, reflecting selective

harvesting rather than total forest clearance. This pattern highlights the ongoing demand for timber, firewood, and construction materials. The dispersed nature of logging shows that resource extraction happens where forest cover is still substantial and accessible, rather than simply in regions with high population density.

Shifting Cultivation (12kha): Shifting cultivation continues to be a major cause of forest disturbance in several parts of Mokokchung. It is most prominent on remote hill slopes and rural hinterlands, particularly in the southern and eastern regions and parts of the western uplands. For many local communities, these traditional rotational practices hold both cultural and economic importance. While shifting cultivation does not always result in permanent forest loss, repeated cycles of clearing and burning prevent full ecological recovery. Over time, this disrupts natural succession, weakens soil cohesion, and leaves steep slopes more prone to erosion. The situation has intensified in recent years as fallow periods have shortened due to population growth, limited land availability, and rising land-use demands. This has led to more fragmented landscapes and increased vulnerability to hazards such as landslides, accelerated runoff, and soil erosion.

Naturally driven disturbances (95ha): Naturally occurring disturbances affect around 95 hectares of Mokokchung. These areas are mainly found on steep, heavily dissected slopes, escarpments, and foothill zones, particularly in the northern and western parts of the district where terrain is inherently unstable. These locations are especially prone to geomorphic processes triggered by rainfall, such as landslides, sheet erosion, slope failures, and tree falls, particularly during periods of intense monsoon rain.

5.2. Land Use land Cover Analysis (1991-2021)

Humans have always shaped the land to meet their practical, social, and cultural needs. This use of land inevitably alters the environment, sometimes with unintended consequences for both ecosystems and human well-being. While natural processes can drive changes in land cover, most changes today are influenced by human activity (Briassoulis, 2011). How land is used and the resulting land cover patterns depend on

a mix of environmental conditions, socio-economic factors, and how people manage these resources over time and space. Land cover refers to the physical state of the Earth's surface, including vegetation, water bodies, and soil types (Turner et al., 1995; Meyer & Turner, 1994). Land use, on the other hand, describes how people actively manage and exploit the land for agriculture, settlements, infrastructure, or other economic and cultural activities (FAO/UNEP, 1999; EPA, 2021). Over time, changes in land use and land cover (LULC) have become central to studies in environmental science, geography, and urban planning because of their wide-ranging effects on ecosystems, climate, and human livelihoods (Roy et al., 2022; Dregne & Chow, 1992).

Understanding LULC is especially important for managing geomorphological hazards. By studying how human activities interact with natural processes, LULC analysis helps reveal areas that are vulnerable to risks such as landslides, soil erosion, and flash floods. For example, forests help stabilize slopes, reduce runoff, and prevent soil loss, while deforested or heavily cultivated land often accelerates erosion and increases slope instability. Mapping and analyzing these patterns over time also helps identify where settlements, farmland, and infrastructure are most at risk, providing a strong foundation for hazard assessment and mitigation planning (Lambin et al., 2001; Geist & Lambin, 2002; Sarkar & Kanungo, 2004; Reichenbach et al., 2018).

By combining spatial data with observations of population growth, agricultural expansion, shifting cultivation, and infrastructure development, LULC studies show how human-environment interactions can amplify hazard susceptibility in fragile hill regions. They also offer a clear picture of exposure and vulnerability, allowing planners to prioritize risk reduction measures and design land-use policies that support both safety and sustainable development.

5.2.1. Materials and Methodology

Satellite imagery from the USGS Earth Explorer portal was used to analyze the study area. LANDSAT 5 images from 1991 and LANDSAT 8 images from 2021 were selected, between the months of November and February to minimize cloud cover (0-5%). The images have a moderate resolution of 30 meters. The analysis was carried out in a GIS environment using supervised classification with the near-infrared, red, and green bands (FCC). Six LULC categories were defined: Agriculture/Farmland, Barren Land, Dense Vegetation, Low Vegetation, Settlements/Built-up, and Water Bodies. The area of each class was calculated by converting pixel counts into square kilometers and generating class statistics.

For change detection, a post-classification comparison was used. The 1991 and 2021 classified maps were cross-tabulated to quantify gains and losses for each LULC class and to understand the transitions between categories. Net changes were calculated by subtracting the 1991 area from that of 2021. This approach provided a detailed picture of how land use and cover have evolved over three decades.

5.2.3. Land Use land Cover Analysis of 1991

The LULC classification of 1991 as illustrated in Figure 5.5 reveals that the study area was predominantly covered by dense vegetation, occupying about 1145.65 km² (70.39%) of the total geographical area. Low vegetation extended across 177.53 km² (10.95%), representing shrubs, grasses, and secondary growth. Agriculture/farmland accounted for 219.35 km² (13.56%), reflecting land under crop cultivation and pasture. Settlement/built-up areas occupied 22.64 km² (1.36%), while water bodies covered 21.43 km² (1.30%), consisting of rivers, lakes, and ponds. Barren land was present over 44.03 km² (2.72%), including exposed soil, degraded patches, and areas affected by shifting cultivation.

5.2.4. Land Use land Cover Analysis of 2021

The LULC classification of 2021 as depicted in Figure 5.5 reveals that the study area was also predominantly covered by dense vegetation, occupying about 1098.56 km² (67.48%) of the total geographical area. Low vegetation extended across 224.17 km² (13.96%), representing shrubs, grasses, and secondary growth. Agriculture/farmland accounted for 173.93 km² (10.76%), reflecting land under crop cultivation and pasture. Settlement/built-up areas occupied 96.06 km² (5.74%), while water bodies covered 29.19 km² (1.80%), consisting of rivers, lakes, and ponds. Barren land was the least represented class, covering 8.52 km² (0.004%), which included exposed soil, degraded patches, and areas affected by shifting cultivation. Figures 5.6a and 5.6b illustrate the LULC class composition for 1991 and 2021.

Table 5.1: LULC Classification Scheme for Mokokchung District, Nagaland.

Sl. No.	LULC Category	Class Description
1.	Agriculture/Farmland	It encompasses all arable land that is used for crop cultivation and pastureland utilized for raising livestock.
2.	Barren Land	Lands filled with exposed soil and aridity affected by human activities. It includes areas under mining and Jhum cultivation.
3.	Dense vegetation	Areas with thick and continuous forest cover, including closed canopy forests, evergreen and semi-evergreen patches, and regions with tall and mature trees. These areas provide strong ecological stability and act as primary forest zones.
4.	Low Vegetation	Areas with sparse or degraded vegetation cover, including shrubs, grasses, fallow land, and young secondary growth. These are often associated with shifting cultivation, abandoned agricultural fields, or degraded forest patches.
5.	Settlement/Built-Up	Areas with structures and buildings characterized by their physical and functional attributes. It includes transportation, roads, commercial, industrial, rural and urban built up land etc.
6.	Water Bodies	Any substantial accumulation of water on the Earth's surface. It includes open water such as lakes, rivers and ponds.

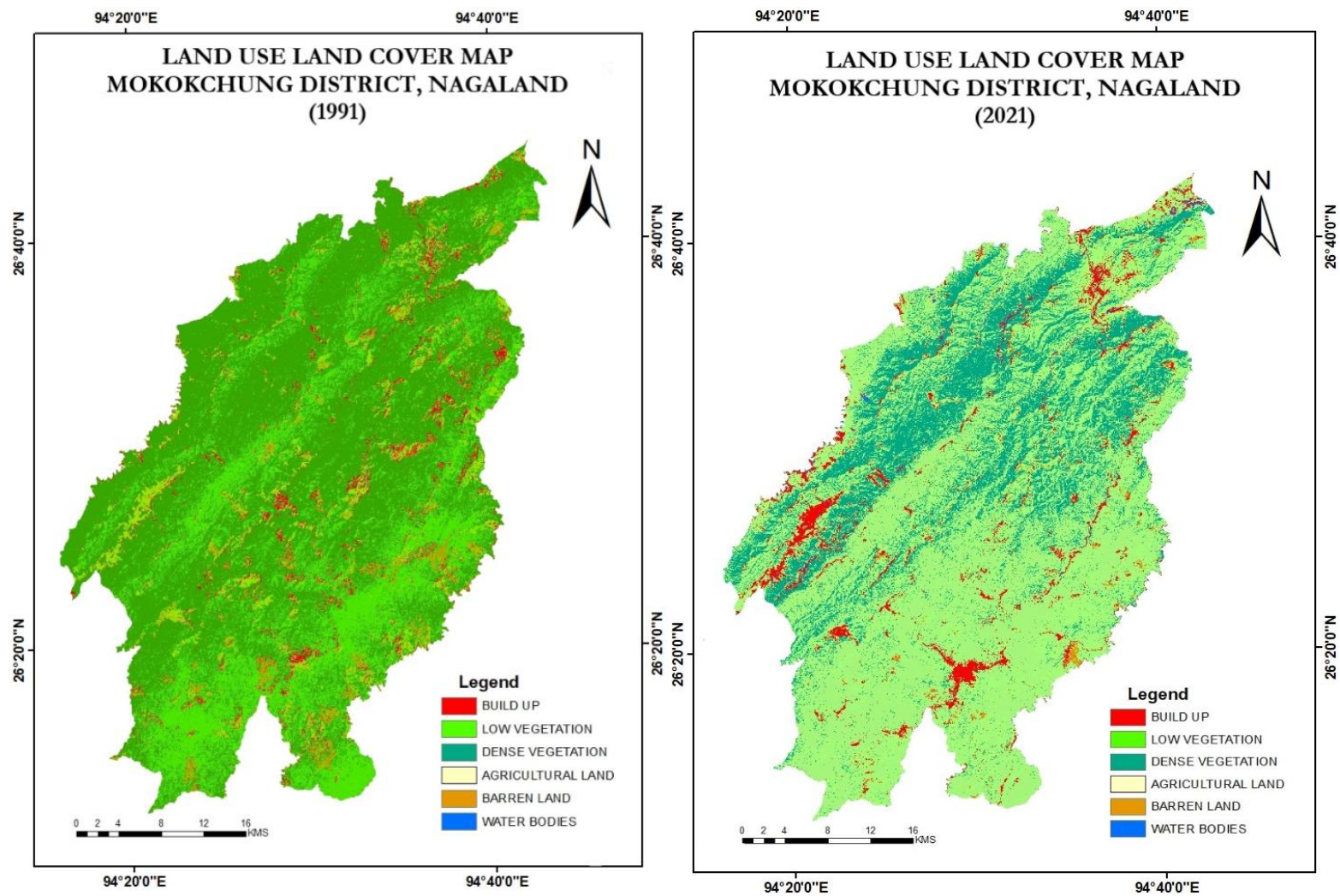


Figure 5.5: Land Use Land Cover Map of Mokokchung District, 1991 and 2001.

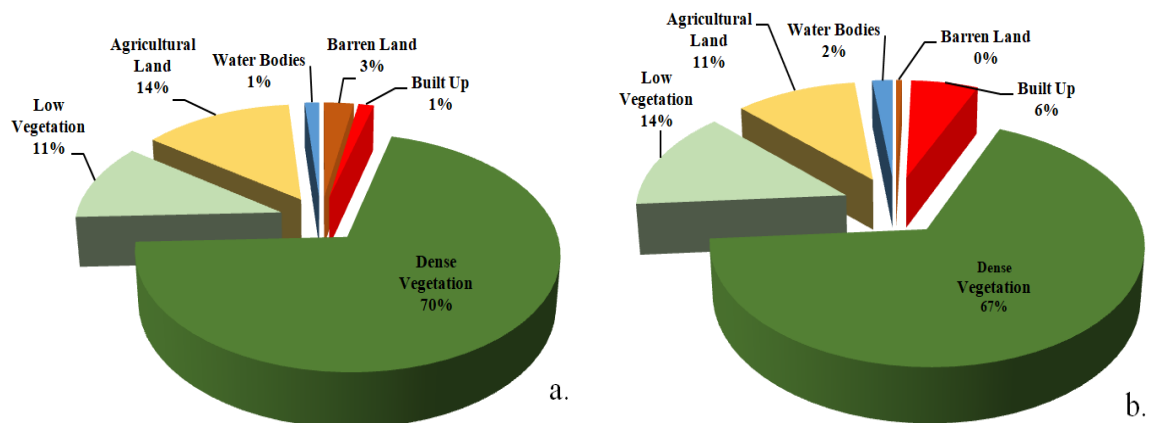


Figure 5.6: LULC Composition of 1991 and 2001.

5.2.5. Dynamics of Land Use and Land Cover from 1991 to 2021: The change detection analysis of Mokokchung District between 1991 and 2021 as shown in Figure 5.7 illustrates the patterns of transition and modification among different land use and land cover (LULC) classes. The analysis presented in Table 5.2 reveals that dense vegetation and agricultural land experienced the largest losses thereby contributing the largest share of land transitions, while built-up areas and low vegetation registered the greatest gains. These dynamics reflect both the long-standing traditional practices of shifting cultivation and the more recent pressures of urbanization and infrastructural development.

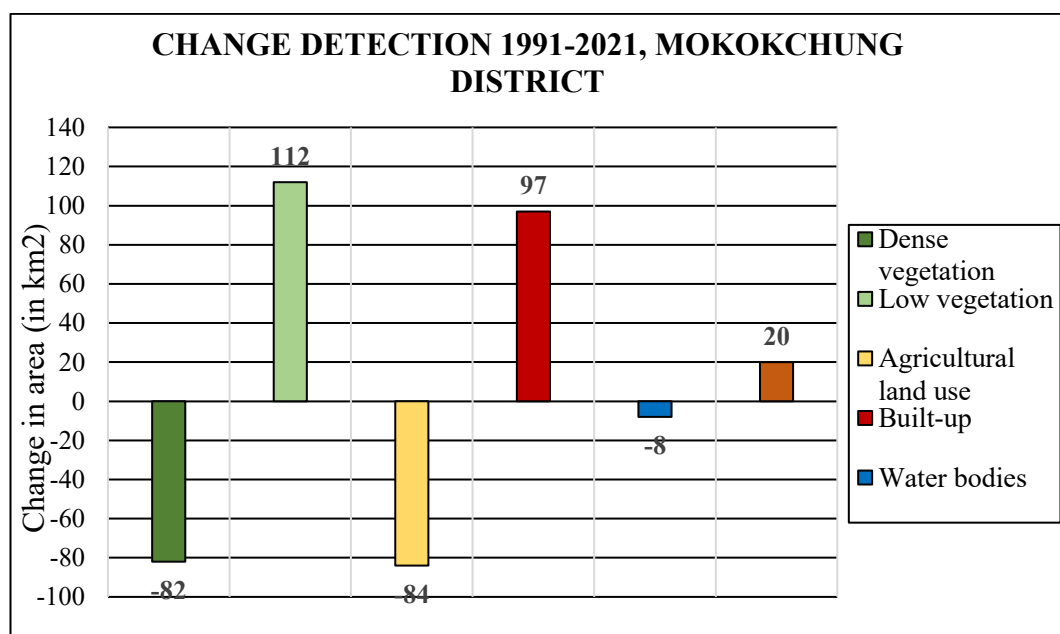


Figure 5.7: LULC Detection of Mokokchung District (1991-2021).

Table 5.2: Change detection analysis of Mokokchung District between 1991 and 2021.

LULC Classes	Change Detection Analysis (1991-2021)	Area in km²
Agricultural Land	Barren Land	2.530
	Build Up	7.317
	Dense Vegetation	25.629
	Low Vegetation	83.239
	Water Bodies	0.207
Barren Land	Agricultural Land	23.440
	Build Up	3.950
	Dense Vegetation	5.724
	Low Vegetation	13.944
	Water Bodies	0.07
Build Up	Agricultural Land	12.666
	Barren Land	0.350
	Dense Vegetation	11.010
	Low Vegetation	12.009
	Water Bodies	1.010
Dense Vegetation	Agricultural Land	448.755
	Barren Land	2.250
	Build Up	32.482
	Low Vegetation	186.070
	Water Bodies	4.519
Low Vegetation	Agricultural Land	29.266
	Barren Land	2.069
	Build Up	24.752
	Dense Vegetation	7.260
	Water Bodies	0.597
Water Bodies	Agricultural Land	0.021
	Barren Land	0.000
	Build Up	0.635
	Dense Vegetation	0.011
	Low Vegetation	0.062

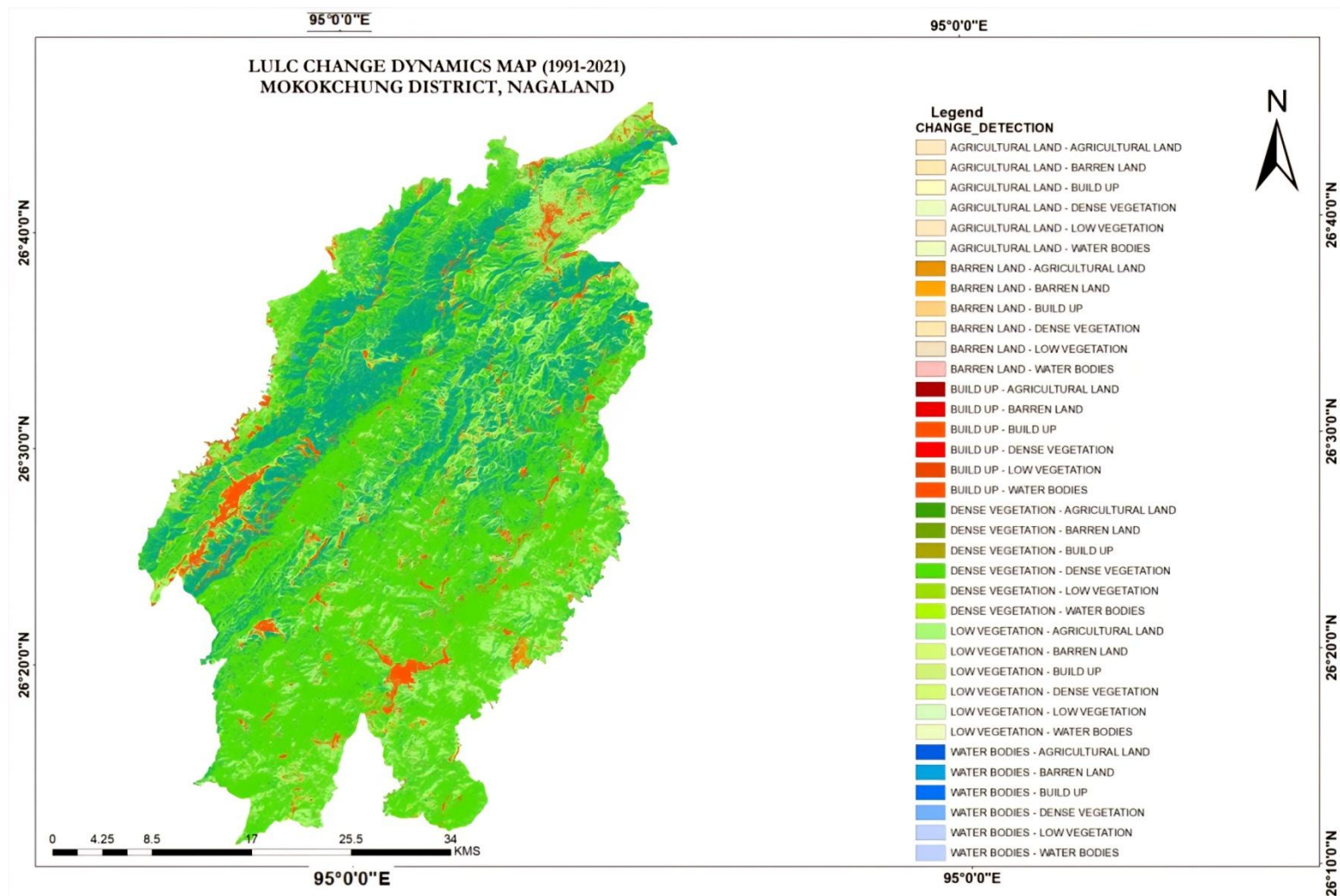


Figure 5.8: LULC Change Dynamics of Mokokchung District (1991-2021).

Although dense vegetation has declined considerably over the study period, it has remained the dominant land cover in Mokokchung district. Large areas of dense forest were converted into agricultural land (448.76 km²), low vegetation (186.07 km²), and built-up areas (32.48 km²). These changes are closely associated with deforestation driven by agricultural expansion, shifting cultivation, road construction, and the ongoing growth of settlements. The steady reduction in dense vegetation reflects increasing human pressure and the persistence of unsustainable land-use practices.

Agricultural land also experienced notable changes. Significant areas were converted into low vegetation (83.24 km²) and dense vegetation (25.63 km²), suggesting both abandonment of farmland followed by natural regeneration and the cyclical patterns typical of shifting cultivation. About 7.32 km² of agricultural land was transformed into built-up areas, illustrating the gradual encroachment of urban development into productive farmland.

Low vegetation emerged as a key transitional category. Much of its increase came from conversions of dense vegetation (186.07 km²) and agricultural land (83.24 km²). However, this class remained unstable, with parts of it further converted into built-up areas (24.75 km²). This pattern suggests that low vegetation often represents degraded or fallow land, which may either recover into denser vegetation or be repurposed for agriculture or settlement.

Built up land underwent the most significant growth during the study period, making urban expansion the most dynamic land-use process in Mokokchung. Settlement areas expanded through the conversion of agricultural land (12.67 km²), dense vegetation (11.01 km²), and low vegetation (12.01 km²). Overall, built up land increased by more than 73 km², representing a substantial and largely irreversible transformation of the landscape into residential, commercial, and infrastructural uses.

In contrast, barren land recorded a marked decline as much of it was converted into agricultural land (23.44 km²) and low vegetation (13.94 km²), indicating some degree of land rehabilitation or productive reuse. Only about 0.88 km² remained barren

by the end of the study period, suggesting that previously degraded lands were gradually absorbed into more active land-use categories.

Water bodies experienced a modest net increase of 7.75 km² between 1991 and 2021. Nevertheless, localized fluctuations were observed, with minor conversions between water bodies and adjacent agricultural or low vegetation areas. These changes likely result from both human interventions, such as the construction of ponds and reservoirs, and natural processes, including sedimentation and seasonal flooding.

The overall change analysis reveals a much complex pattern. Although certain positive developments such as the reduction of barren land are evident, they are also outweighed by the substantial losses of dense vegetation and agricultural land. The rapid expansion of built up areas represents an irreversible land transformation with significant ecological implications. At the same time, the growth of low vegetation highlights transitional degradation linked to shifting cultivation and farmland abandonment. Together, these trends emphasize the urgent need for sustainable land management and balanced development strategies in Mokokchung.

5.3. Road Construction and Slope Destabilization

Road construction is a major factor shaping the landscape in steep, hilly areas, and it often comes with serious environmental consequences. Building roads can destabilize slopes, alter natural drainage patterns, accelerate soil erosion, and even trigger landslides or mass movements of soil and rock. When road construction proceeds without careful attention to geological, geomorphological, and ecological factors, these effects are amplified, leading to long-term land degradation and weakening the resilience of local ecosystems.

In Mokokchung, the push for better connectivity through national highways, district roads, and inter-village links has involved extensive earthworks, hill cutting, and modifications to natural drainage channels. While these projects improve accessibility, they have also made the district more prone to geomorphic hazards, particularly landslides and land subsidence. Poorly designed drainage systems,

uncontrolled spoil disposal, and extensive slope cutting along some of the main routes have left several areas persistently unstable, highlighting the need for careful planning and mitigation measures during road development.



Plate 5.1: Rock Debris along a road cut, indicating shallow slope failure triggered by excavation and rainfall.



Plate 5.2: Road cut debris triggering slope instability and distorting vegetation.

The Mokokchung-Mariani road (National Highway 702D) clearly illustrates the problems caused by road construction on fragile slopes. In areas around Chungtia, Mekuli, Aliba, and Changki villages, repeated hill cutting and undercutting for road

widening have left slopes highly vulnerable, creating at least five major landslide prone spots. Poor drainage along the road means the surface often stays wet for much of the year, which only worsens slope instability during the monsoon. Similarly, along the Mokokchung-Amguri road, especially near Changtongya, Liroyim, and Merangkong villages, landslides are a recurring issue during heavy rains. These slope failures not only damage the road itself but also disrupt the movement of people and goods, showing how poorly drained roads on already weak slopes can amplify natural vulnerabilities.



Figure 5.9: Slope failures along road-cut sections in Mokokchung District.



Plate 5.3: Field observation of road cutting related slope failure illustrating weakened slope structure, loose debris and signs of continued mass movements.



Plate 5.4: Subsidence related slope failure affecting road infrastructure.

In addition to major landslides, smaller mudslides and minor slope failures frequently occur on steep terrain during heavy rains, often linked to road cuttings and the build-up of construction debris on unstable slopes. Land subsidence is another

significant concern for road infrastructure. Along the Mokokchung-Mariani road, two notable sinking zones have been identified: one near Changki village and the other near Chungtia village. These areas are particularly vulnerable due to weak subgrade conditions, which have been worsened by road construction and changes in water flow caused by compacted surfaces and poor subsurface drainage. As a result, the road surface in these zones deforms continuously, requiring ongoing maintenance and adding substantially to the long-term costs of road management.

5.4. Variability in rainfall

Climate change, particularly rising temperatures and shifting rainfall patterns, has been linked to more intense weather events in many mountainous areas. In places like Mokokchung, where the terrain is steep and the geology is fragile, even small changes in rainfall can trigger landslides and other geomorphological hazards. Studies in Himalayan regions have shown that erratic monsoons and heavy downpours can quickly destabilize slopes and set off a chain of geomorphic processes (Ives & Messerli, 1989; Shrestha & Aryal, 2011). The way rain affects slopes is both hydrological and mechanical: intense or prolonged rainfall saturates the soil, increases pore water pressure, and lowers the soil's effective stress, all of which reduce slope stability and can lead to landslides (USGS, 2023). With climate models predicting more frequent and heavier rainfall events in the future, areas like Mokokchung are likely to become even more vulnerable. This makes understanding not just how much it rains, but how long and where the rain falls, essential for hazard assessment, predictive modeling, and disaster preparedness (Fowler et al., 2021; Gonzales et al., 2023).

5.4.1. Rainfall Pattern

In Mokokchung District, the influence of south-west monsoon from the months of June to September is especially critical, as this period accounts for the majority of the annual rainfall and is closely related with increased occurrence of flash floods, landslides debris flows, accelerated soil erosion, and widespread slope failures. Figure 5.10

presents the long-term trends and variability of rainfall in both total annual rainfall and monsoonal rainfall in Mokokchung district over the span of 15 years.

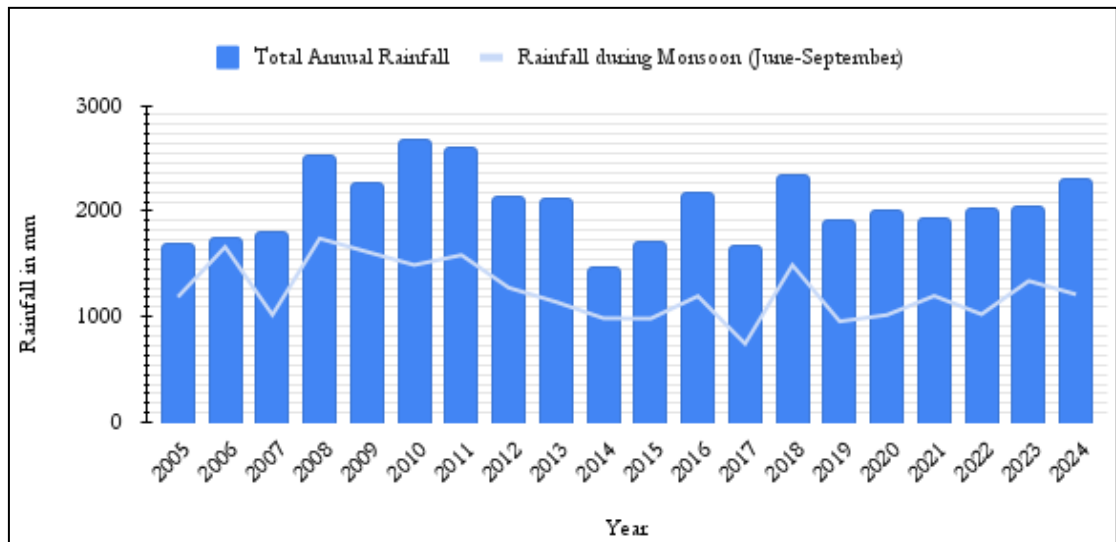


Figure 5.10: Annual and monsoonal rainfall variability in Mokokchung District (2005-2024).

Mokokchung receives high precipitation during the June-September monsoon, which dominates the hydrological regime. In most years, annual rainfall in Mokokchung has remained above 2000 mm, with pronounced peaks recorded in 2010, 2011, 2017, 2018, and 2024. These particularly wet years correspond with recorded incidents of flash floods and landslides in the district, highlighting the strong relationship between extreme rainfall events and hydro-geomorphological hazards. Such patterns suggest that years of exceptionally high rainfall not only increase water discharge in small catchments but also act as triggers for rising hazards, including flash floods, accelerated soil erosion, and slope failures. Prolonged saturation during intense monsoon periods reduces soil shear strength and enhances subsurface water infiltration, thereby destabilizing slopes. The region's steep topography and fragile lithology further amplify this vulnerability. Additionally, anthropogenic interventions such as road cutting, slope modification, and expansion of settlements have altered natural drainage and slope geometry, significantly increasing susceptibility to rainfall induced failures. It is however necessary to understand that hazard occurrence is not confined to above average rainfall years. Even in years with lower total rainfall, short

duration, high intensity monsoon showers can trigger localized flash floods, particularly in areas where drainage channels are obstructed or when cultivation areas are close to stream banks. This indicates that hazard severity depends not only on cumulative annual rainfall but also on rainfall intensity, duration, and spatial concentration. Intense convective storms, combined with inadequate surface drainage, can quickly exceed catchment capacity, leading to sudden runoff surges and localized geomorphic disturbances.

5.4.2. Analysis of Rainy Days

The analysis of rainy days in Mokokchung district between 2005 and 2024 (Figure 5.11) shows a clear declining trend, as indicated by the negative slope of the trend line ($R^2 = 0.35$). While inter annual variability is evident with peaks in 2010 (138 days) and 2014 (143 days): the overall direction points towards a reduction in the number of rainy days over time. By the early 2020s, the district frequently recorded just around 103-110 rainy days annually, a marked decrease from the 130-140 days observed in the mid 2000s. This decline indicates that rainfall is increasingly concentrated within fewer days, even though the total annual rainfall has not decreased proportionally. Such a shift implies a rise in high intensity rainfall events occurring over shorter durations. In mountainous regions like Mokokchung, this pattern significantly increases hazard risk particularly in steep slopes and densely populated valleys where drainage capacity is limited. This trend reflects the growing influence of climate variability and climate change. Fewer rainy days combined with more intense downpours are reshaping the district's geomorphological hazard profile. As rainfall becomes more episodic and extreme, the likelihood of slope failures, flash floods, and accelerated soil erosion correspondingly increases, contributing to a more unstable and unpredictable hazard environment.

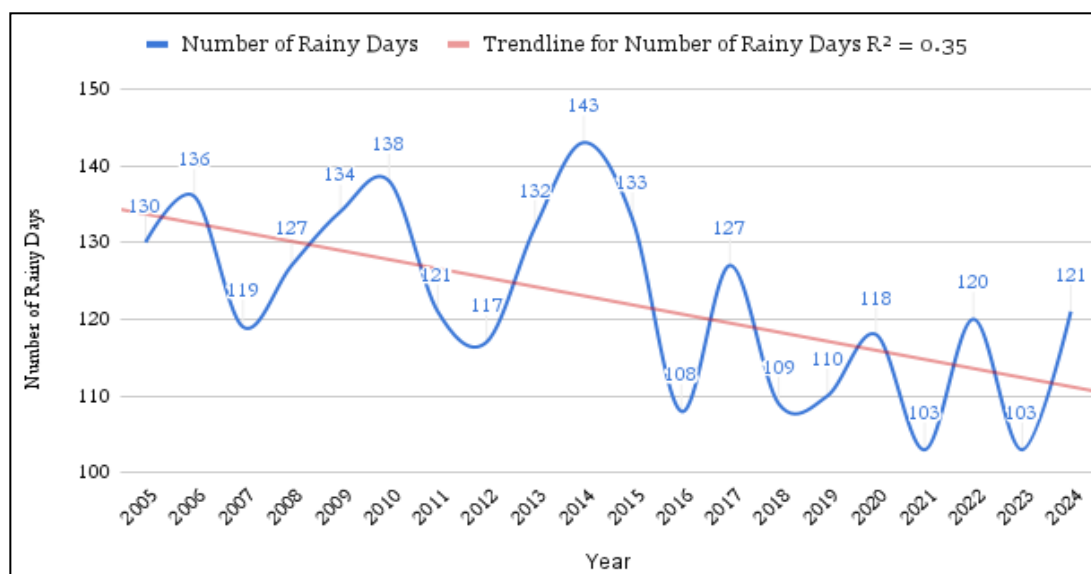


Figure 5.11: Annual trends of rainy days in Mokokchung District (2005-2024).

5.5. Landslide Activity and Inventory Mapping in Mokokchung District, Nagaland

A number of factors including the type and severity of landslides, research purpose, research areas, mapping scales, and the availability and constraints of data define the selection of an appropriate approach for landslide assessment (Guzzetti et al., 2000; Guzzetti et al., 2012; Van Westen et al., 2005; Shano et al., 2020). Mokokchung district of Nagaland is characterized by moderately weak topography and a young mountainous terrain, and it receives abundant rainfall during the monsoon. Consequently, landslides represent one of the most active and recurring geomorphological hazards in the region. Slope instability is widespread across Mokokchung, caused not only by natural factors like steep gradients, fragile lithology, and intense rainfall, but also by anthropogenic interventions. Activities such as road construction, slope cutting, and unplanned housing development significantly disturb natural slope equilibrium, increasing the likelihood of failure. Given these conditions, it is essential for planners and decision makers to prioritize geological stability and environmental suitability when selecting sites for road networks, urban expansion, and infrastructure projects. Incorporating slope stability assessments, proper drainage

planning, and environmentally sensitive construction practices can substantially reduce landslide risk and enhance long term resilience in the district.

A landslide inventory plays a crucial role in landslide studies, whether for creating hazard zonation maps or establishing early warning systems. It includes the locations and characteristics of past landslides across various temporal and geographical scales (Genene & Meten, 2021; Guzzetti, 2003; Guzzetti et al., 2005; Shano et al., 2021; Alamrew et al., 2024). Such an inventory provides essential information about the distribution and nature of landslides, which is vital for regional-scale hazard evaluation and mitigation.

In this context, a landslide inventory map of Mokokchung district, Nagaland was prepared through the interpretation of Google Earth Images and GPS data collected during a comprehensive field study which is shown in Figure 5.12. The locations of landslide occurrences were verified and assessed to determine their types and extent. A total of 346 landslides were recorded in the study area, which covers approximately 651 km² of the district's total area. A high density of landslides was observed in the northern parts of the study area. The most common types of landslides found were debris slides, debris flows, slope failures, and slumps. Landslide characterization and mapping were conducted using detailed interpretations of inventory data, satellite imagery, and field derived information, all integrated with Google Earth observations. Areas with flat or gently sloping topography generally showed low landslide activity, while steep, dissected terrains had a high concentration of slope failures.



Plate 5.5: Post-landslide terrain disruption with damaged access routes and altered slope in Chungtia village.



Plate 5.6: Active slope failure in a settlement, showing exposed soil and unstable terrain in Chungtia village.



Plate 5.7: Deep seated, debris slide involving the downward movement of weathered rock and soil mass along a slope failure.

Table 5.3: Classification of landslide types in Mokokchung District.

Sl. No.	Types of slides	Number	Percentage
1.	Debris Slide	178	51
2.	Debris Flow	143	42
3.	Debris Slide cum Rotational Slide	13	3.9
4.	Rock Slide	7	2.09
5.	Debris Slide cum Rock Slide	3	0.75
6.	Debris Flow and Rock Fall	2	0.26
Total		346	100

Source: Field Work (2022-2024).

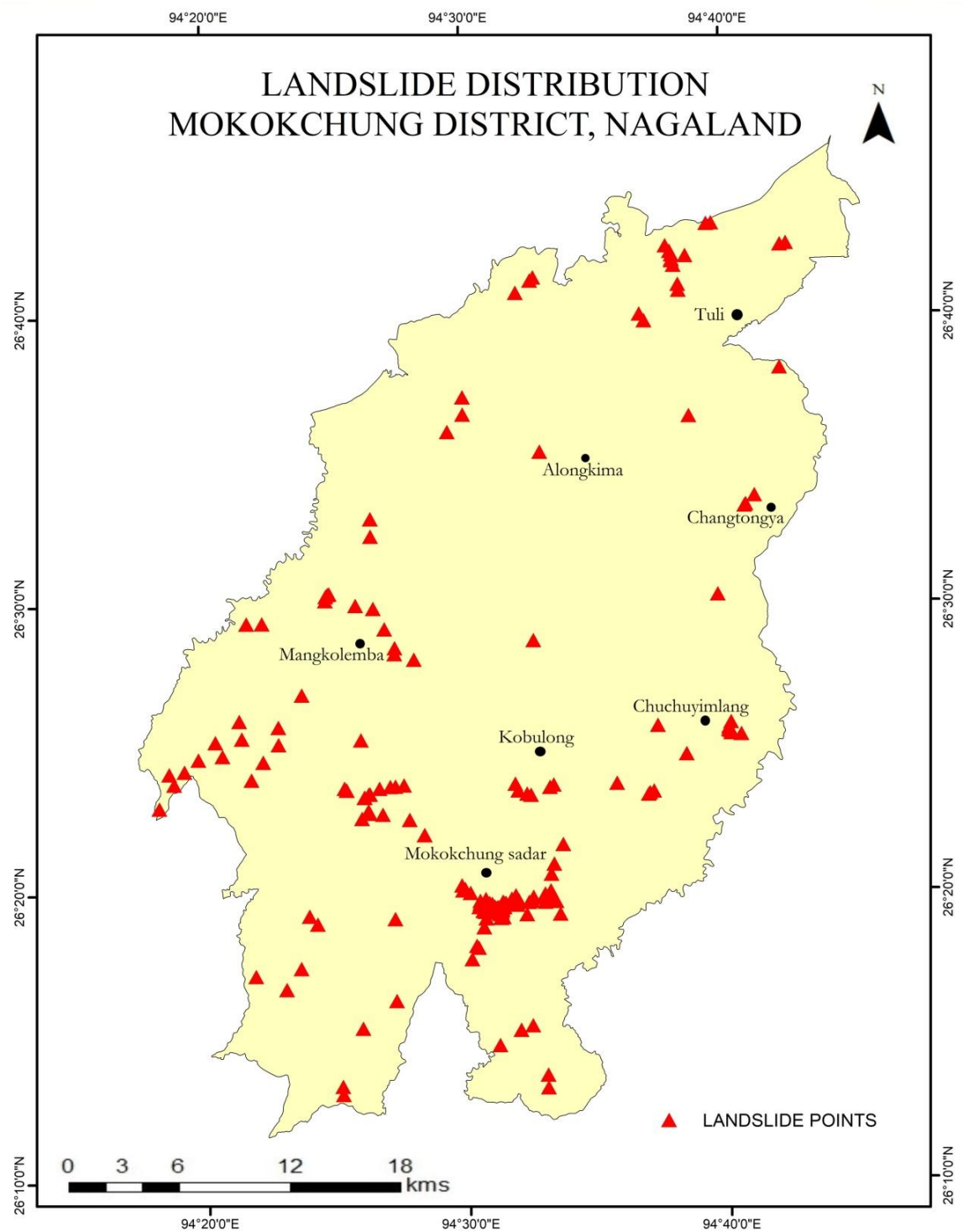


Figure 5.12: Landslide Distribution Map of Mokokchung District.

The landslide inventory map (Figure 5.12) shows that landslides are most densely clustered in the southern, southwestern, southeastern, and central parts of the district, corresponding closely with the moderate to very high hazard zones on the landslide hazard map. Most of these landslides occur along structural and lithological boundaries and are common on dissected ridges, road cuts, and valley edges. In the southwestern part of Mokokchung, landslides are particularly concentrated in areas classified as very high hazard. These areas have steep slopes, dissected terrain, and many roads. The landslides here include debris flows, earth slides, and rock falls, mostly on slopes with weathered rocks and residual soils. These slopes also experience strong gully erosion and high groundwater, often showing signs of active movement. In the southeastern villages, landslides are more scattered but still significant in moderate to high hazard areas, especially where human activities like road cutting have disturbed slopes. The terrain is undulating, with weathered rocks and colluvial soils. Landslides here are mainly rotational and translational slides, with occasional topples and shallow debris flows. Groundwater and lineaments add to slope instability, often affecting farmland and rural roads. Central areas of the district experience fewer landslides, but they tend to occur where roads cut across steep slopes, creating localized instability. The terrain consists of highly weathered bedrock interspersed with farmland and settlements. Landslide types include slow creep, rock topples, and slides, many of which show signs of reactivation such as ground cracks, tilted trees, and the emergence of springs. In the northern and northeastern parts of the district, landslides are relatively scattered and mostly follow stream valleys and escarpments. Even though these areas are classified as low to moderate hazard, local conditions like river undercutting, steep slopes, and residual soils can still trigger slope failures. Earth slides and rock slides are the most common, often impacting agricultural land and the edges of settlements. In the northwestern region, landslide activity is linked to high elevation ridges and fault zones, reflecting the underlying geological structures. These are generally large scale failures occurring in residual soils over bedrock. Observations suggest that many of these landslides occur during the late monsoon season (August-September), highlighting the critical role of heavy rainfall as a major triggering factor.

5.6. Flash Flood hazard and Vulnerability in Mokokchung District

Traditionally, flash floods in Mokokchung district mostly happened along rivers, affecting agricultural fields on floodplains and terraces. Sudden rises in water would deposit sediments onto crops, but settlements were generally safe, so these floods were seen largely as a river based problem. In recent years, the nature of flash flood risk in Mokokchung has changed noticeably. Flash floods are increasingly reported within towns and villages, indicating a shift from predominantly rural occurrences to more urban centered impacts. Rapid urban expansion, construction along stream banks, encroachment into natural drainage channels, and inadequate stormwater management has all increased vulnerability. Short but intense rainstorms often overwhelm drains and small streams, leading to sudden flooding of homes, markets, and roads. As a result, flash floods are no longer just a rural concern they have become a serious urban hazard, threatening livelihoods, property, and mobility. Even though these events often affect relatively small areas, their sudden onset makes them extremely dangerous, leaving little time for warning or evacuation. Settlements along streams, river terraces, and low lying urban wards are particularly at risk during intense convective storms. The district's steep slopes and narrow valleys intensify the hazard by speeding up runoff and increasing flow velocity, making floods more forceful and destructive. At the same time, the rugged terrain makes monitoring and forecasting difficult, as localized downpours may not be fully captured by conventional rain gauge networks, limiting early warning capabilities. Flash floods in Mokokchung are often linked with other hazards. Heavy rains can carry sediments, erode stream banks, and trigger landslides or debris flows, compounding damage to farms, roads, and infrastructure. Overall, these floods show how extreme monsoon rains, climate variability, and fragile hilly environments combine to heighten risk. Addressing the problem requires more localized monitoring, improved early warning systems, watershed conservation, slope management, and community based preparedness.

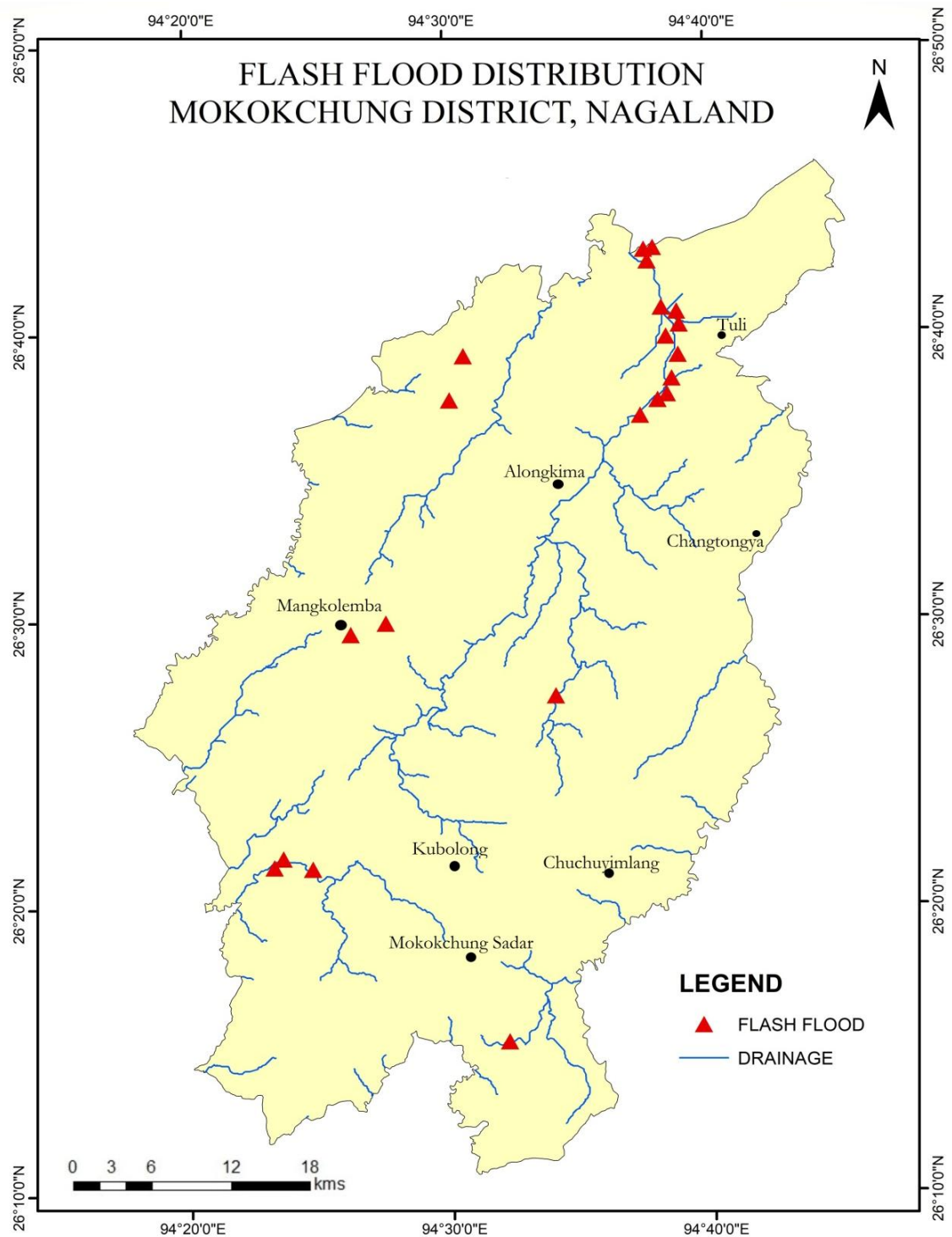


Figure 5.13: Flash Flood Distribution Map of Mokokchung District.

5.6.1. Major Flash Flood events in Mokokchung

Mangkolemba Flash Flood (2022): Mangkolemba is a town and sub-division of Mokokchung district, Nagaland. It is located between Jangpetkong and Japukong ranges. It lies between 26° 29' 55" N Latitude and 94° 26' 11" E Longitude at an altitude of 914 meters above mean sea level. It is situated at a distance of 40 km from Mokokchung town. Mangkolemba is the sub-divisional headquarter of three ranges viz. Jangpetkong, Japukong and Tsurangkong covering about 40 villages. The local catchment covers approximately 200 hectares and displays a dendritic drainage pattern, which is known to produce high magnitude flood peaks at basin outlets (Mukhopadhyay, 1999). The terrain varies from moderate to high relief, with elevations ranging from 320 to 795 meters above sea level. Like much of Nagaland's hilly landscape, Mangkolemba is exposed to a variety of natural hazards. The town is situated at the confluence of small tributary streams descending from steep slopes, within a narrow valley where drainage convergence increases susceptibility to flooding. While heavy downpours and flash floods have historically been infrequent in the region, recent years have seen these events becoming more common, likely due to changing climatic patterns that intensify localized rainfall. At the same time, rapid human activity including unplanned settlement growth, infrastructure development, mining, and expansion into hazardous zones has amplified the impact of these events. Geomorphologically, the area is dominated by fluvial deposits, colluviums, and old landslide masses, which are largely unconsolidated. During heavy rainfall, these deposits become saturated, raising pore water pressure and triggering slope failures, landslides, and debris flows. Streams in the region have steep gradients, giving them high energy capable of transporting sediments, undercutting slopes, and eroding banks. Human activities exacerbate the problem as villages and houses are often built on loose sediments and fan deposits close to streams, while road cutting, coal mining, and other construction along valley sides further weaken slopes.

A vivid example occurred on August 10, 2022, when Mangkolemba experienced an intense overnight rainfall of 135 mm, which triggered a major flash flood. Local

streams and tributaries swelled rapidly and overflowed, carrying boulders, sediments, and debris.



Plate 5.8: Vehicles inundated by debris flow in Mangkolemba.



Plate 5.9: Houses exposed to debris flow during flash flood in Mangkolemba.

The flood caused widespread damage to houses, farmland, and essential infrastructure. Settlements along stream banks and on unconsolidated deposits were the hardest hit. The storm, convective in nature, produced heavy downpours within a small catchment, and the steep terrain accelerated surface runoff. Poor drainage and settlement expansion along valley margins worsened water accumulation,

overwhelming small culverts that could not handle the discharge. Several houses were damaged, one collapsed entirely, and vehicles and machinery were swept away. Roads and culverts were washed out, cutting off access to surrounding areas, and about a dozen families were displaced. The event had a profound impact on both residents and neighboring communities. Rivers overflowed, with some even changing course under the relentless rainfall. It illustrated a clear shift in flash flood hazards from primarily riverine areas to inhabited settlements where human infrastructure is now directly exposed to extreme events.

Moalenden Flash Flood (2024): Moalenden is a village located within the Ongpangkong range of Mokokchung district, lying adjacent to the Tzütsüng River, which supports extensive agricultural lands and serves as a critical source for local irrigation. It lies between 26° 25' N Latitude and 94° 52' E Longitude at an altitude of 732 meters above mean sea level. The village is situated in a narrow valley setting, where steep slopes and tributary confluences enhance susceptibility to rapid runoff and flood hazards. The catchment is characterized by a dendritic drainage pattern, which according to hydrological studies, facilitates the quick concentration of flow peaks at basin outlets. Such physiographic and drainage conditions make it highly vulnerable to sudden, intense storms that can trigger destructive flash floods.

On April 19, 2024, the village experienced an unusually heavy convective storm. The localized downpour produced rapid surface runoff and concentrated flow that overwhelmed the Tzütsüng irrigation dam and local streams. Saturated soils and steep slopes prevented water from soaking into the ground, causing a sudden surge of water carrying sediment and debris. The flood breached the irrigation dam and spread across the valley, causing widespread destruction. Over 200 rice and vegetable fields were washed away, severely affecting 182 families and partially impacting 31 more. 24 family owned fishery ponds were destroyed, threatening local food security and markets. Infrastructure also suffered: the irrigation dam collapsed, agri-link roads were eroded, and the Tzütsüng Bridge connecting Moalenden to Tuensang district was damaged by landslides and flooding, disrupting regional connectivity. Several irrigation schemes and water sources were lost, further affecting future cropping

cycles. The disaster's timing worsened its impact, coinciding with a critical stage in the agricultural season. Livelihoods dependent on rice, vegetables, and fisheries were severely disrupted, forcing urgent appeals for relief and rehabilitation. Emergency assessments were carried out by district officials and support agencies, while community leaders emphasized the need for long-term resilience strategies.

The April 2024 flash flood in Moalenden was thus the outcome of an intense convective rainfall event, rapid surface runoff on steep and saturated slopes, and channel convergence within a fragile valley system. The damage was further intensified by anthropogenic pressures, such as settlement and agricultural expansion along valley margins. This event highlights how intense, localized rainfall, combined with fragile geomorphology and human-induced vulnerabilities, can lead to severe losses of infrastructure and livelihoods in the hilly regions of Nagaland.

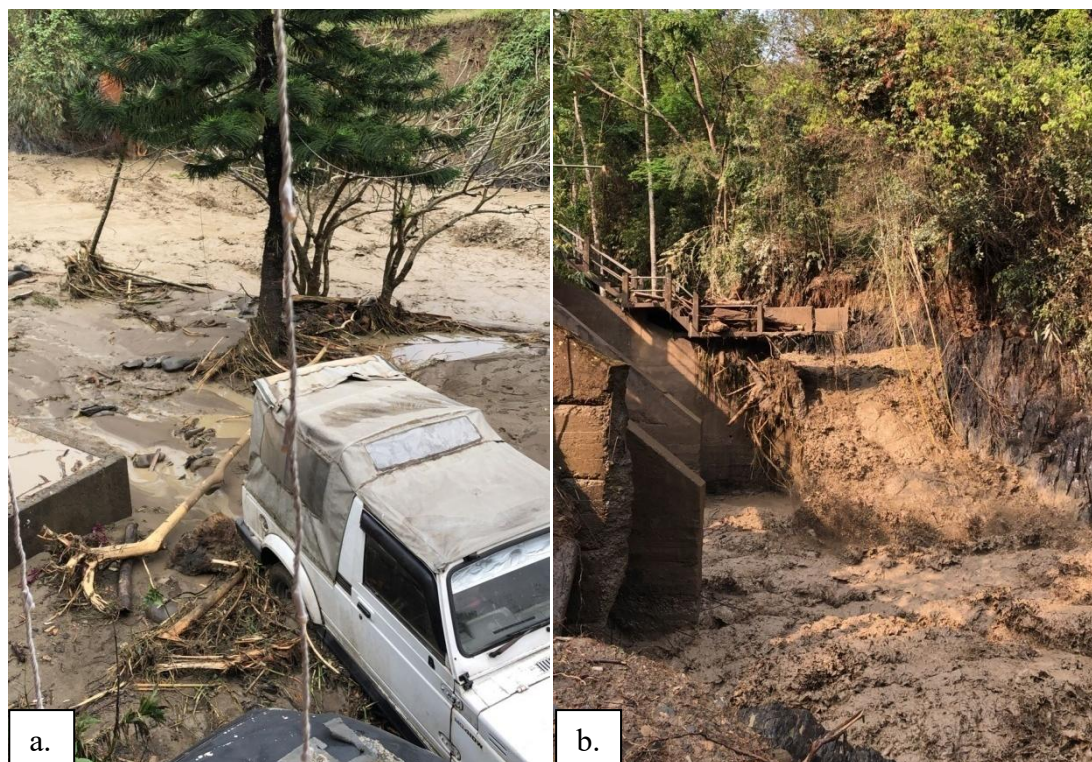


Plate 5.10: (a.) Breached Tzützüng irrigation dam, with structural collapse caused by excessive runoff and debris flow, (b.) Flash flood impacts: debris and sediment deposition damaging vehicles and homesteads near the riverbanks.

5.7. Vulnerability of Settlements to Earthquake hazard in Mokokchung District

Understanding where settlements are located in relation to earthquake hazard zones is important for assessing risk and planning mitigation (UNDRR, 2022). The way communities are spread across areas of different seismic risk reflects not only population patterns but also differences in infrastructure, preparedness, and resilience (Wisner et al., 2014). Mapping settlements against seismic hazard zones provides valuable insight into which rural and urban settlements are more likely to be affected by an earthquake (USGS, 2023). The representation of settlement vulnerability in relation to earthquake risk has been illustrated in the seismic hazard zonation map of Mokokchung district (Figure 5.14). Rural settlements make up about 82% of all mapped points and are mostly spread across moderate and high hazard zones. Significantly, dense clusters of rural settlements are concentrated in the southern belt of the study, characterized by high seismic risk. Some rural communities even fall within very high hazard zones, showing their vulnerability to severe earthquake impacts. While urban settlements, about 18% of the total, are mainly located in moderate and high hazard zones, with a small portion in the very high hazard zone. This spatial distribution is indicative of contrasting vulnerabilities: rural areas characterized by extensive diversion face challenges of accessibility and specific preparedness measures, whereas urban areas are susceptible to increased risks resulting from population density and infrastructural concentration.

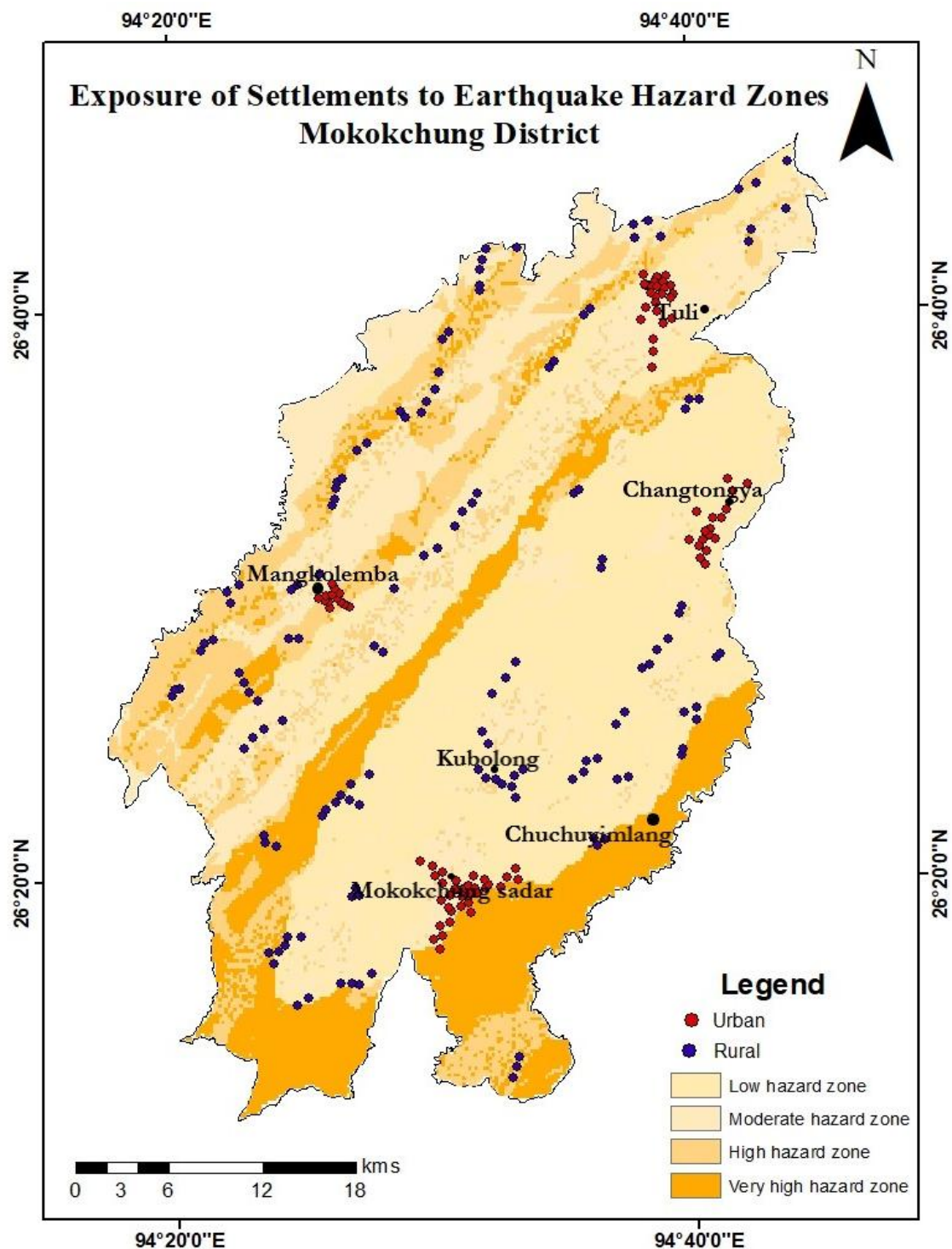


Figure 5.14: Exposure of Settlement to Earthquake hazard zones in Mokokchung District.

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DISASTER RISK GOVERNANCE: FRAMEWORKS, STRATEGIES, AND IMPLEMENTATION

6.1. Overview of Disaster Management in India

India is highly vulnerable to a variety of natural as well as human induced disasters due to its unique geo-climatic features and socio-economic diversity. The country is faced with major risks from earthquakes, landslides, floods, droughts, cyclones, avalanches, and forest fires. Around 60% of the landmass is susceptible to earthquakes varying from moderate to very high intensity. Over 40 million hectares, constituting 12% of the land, are at risk of flood and river erosion. Of the 7,516 km coastline, approximately 5,700 km is vulnerable to cyclones and tsunamis. Furthermore, 68% of the cultivable area is exposed to drought, while hilly regions face risks from landslides and avalanches. According to the report of World Risk Index 2024, India ranks third in highest disaster risk worldwide. The multi-hazard profile of India, necessitates a comprehensive mechanism for disaster management, encompassing both planning and implementation. According to the report of the United Nations Office for Disaster Risk Reduction (UNDRR), a total of 79,732 people lost their lives and 108 crore people were affected in 321 incidences of natural disasters in India between 2000-2019. According to the same report, India suffered nearly 80 billion USD in economic losses in 20 years. In response to the considerable loss of life, property and resources resulting from recurrent disasters, the Indian government and various sectors have implemented various disaster management initiatives to tackle the problem. Formulations at the national level have been adopted by respective states and districts, driven by different factors including the types of disasters prevalent in specific regions.

6.1.1. Legal framework for Disaster Management

The legal framework for disaster management in India is designed to ensure a coordinated and effective response to disaster, promoting resilience and preparedness across all levels of society.

Disaster Management Act 2005: The Disaster Management Act of 2005 corresponds to a significant legislative development in India, drastically modifying the framework for disaster management. The National Disaster Management Authority (NDMA) was established to lead and implement a comprehensive disaster management strategy. This act highlights an organized approach that prioritizes prevention, preparedness and planning over simply response.

National Policy on Disaster Management 2009: The National Policy on Disaster Management 2009 seeks to establish a secure and disaster-resilient India. This approach fosters a comprehensive and technology oriented strategy for disaster management. The policy emphasizes the significance of:

- i. Community engagement in disaster management.
- ii. Enhancing capacity across all levels and
- iii. Incorporating disaster management into development planning.

National Disaster Management Plan 2018: The National Disaster Management Plan 2018 provides a detailed framework for handling disasters in India. It covers all stages of disaster management: prevention, preparedness, response recovery, and rebuilding. Considering India's vulnerability to disasters, the plan follows a multi-hazard approach. It involves not only government agencies, but also the private sector, local communities, and other stakeholders. This plan also aligns with international frameworks to ensure a well co-ordinated and effective disaster response.

The Disaster Management Act 2005, the National Policy on Disaster management 2009, and the National Disaster Management Plan 2018 constitute essential elements of the legal framework for reducing disaster risks and managing disaster response in the country.

6.1.2. Institutional Structure of Disaster Management: Disaster management is an important part of governance in India because the country is vulnerable to many types of natural and human-made disasters. Over time, particularly in response to major disasters, India has developed a comprehensive legal and institutional framework to manage disaster risks more effectively. The country's disaster management system operates at four interconnected levels i.e., national, state, district, and local. At the national level, the National Disaster Management Authority (NDMA) serves as the apex body, while the State Disaster Management Authorities (SDMAs) and District Disaster Management Authorities (DDMAs) operate at the state and district levels separately. This framework functions in a hierarchical and coordinated manner, where higher authorities provide policy guidance and support to lower administrative levels. This structured system enhances coordination, timely decision making, and strengthens the overall effectiveness of disaster preparedness, response, and recovery across the country. The structure involves multiple stakeholders, including various relevant ministries, government departments, along with many other organizational entities coordinating their activities in order to effectively prepare and carry out response, relief and rehabilitation during disaster which has been briefly discussed as under:

National Disaster Management Authority (NDMA): It is the apex body constituted to develop policies and approve the national disaster management plans, in addition to coordinating the enforcement and implementation of the policy and plan for disaster management. It is also responsible for overseeing the National Disaster Response Force (NDRF).

State Disaster Management Authorities (SDMAs): Each states of India have been allotted its own State Disaster Management Authority (SDMA). The SDMA regulates disaster management initiatives at the state level and collaborates closely with the NDMA to carry out national plans.

District Disaster Management Authorities (DDMAs): At the district level, the District Disaster Management Authority (DDMA) is responsible for planning, coordinating, and implementing disaster management activities according to national

and state guidelines. It makes sure that relief and response efforts meet local needs during disasters.

Local authorities: Local authorities, such as village councils and municipalities an important role in managing disasters at the community level. They implement disaster management plans on the ground and ensure that local resources are used effectively during emergencies.

National Disaster Response Force (NDRF): It is a specialized force created to respond quickly to disasters and emergency situations. It was formed by upgrading eight battalions of Central Paramilitary Forces. The NDRF is specially trained and equipped to handle rescue and relief operations during disasters.

National Crisis Management Committee (NCMC): The National Crisis Management Committee (NCMC) is set up by the Government of India to coordinate and supervise relief operations during major natural disasters. It is chaired by the cabinet secretary and includes secretaries of different ministries and departments involved in disaster management. Its main role is to ensure proper command, control, and coordination of disaster response and to guide the Crisis Management Group (CMG) when needed.

Crisis Management Group (CMG): The Crisis Management Group deals with relief and response issues after major natural disasters. It works under the guidance of the NCMC to ensure timely and effective disaster relief operations. The functions of CMG include reviewing contingency plans developed by various ministries, measures necessary for addressing natural disasters, and coordinating the activities of central ministries and state governments concerning disaster preparedness and relief.

Control Room (Emergency Operation Room): The functions of the control room include the collection and dissemination of information regarding natural disasters and relief efforts, maintaining direct communication with the governments of affected states, engaging with various central ministries, departments, and organizations regarding relief coordination, preserving comprehensive records of pertinent action

and contact points within central ministries, and ensuring current information on all relevant officials at both central and state levels.

Planning and Funding mechanism: The policy and funding mechanism for providing relief assistance to individuals impacted by natural disasters is specifically laid out. These are evaluated by the Finance Commission appointed by the Government of India every five years. The Finance Commission recommends the allocation of tax and non-tax revenues between the central and state governments, as well as policies for the provision of relief aid and their corresponding expenditure shares.

Contingency Action Plan: The Government of India has prepared a National Contingency Action Plan (CAP) to deal with emergencies caused by natural disasters. This plan is updated regularly in order to stay effective. It helps ensure that relief operations can begin quickly and smoothly. The CAP clearly defines the roles and responsibilities of different central ministries and departments, sets out standard procedures, and identifies the key authorities responsible for disaster response.

State Relief Manuals: Every state has its own Relief Manual or Relief Code. These documents clearly describe the responsibilities of government officials during natural disasters. They act as practical guidelines for managing relief operations. States regularly update these manuals based on lessons learned from past disasters and changing requirements.

Calamity Relief Fund (CRF): Based on the recommendation of the Eleventh Finance Commission, each state in India maintains a Calamity Relief Fund (CRF). This fund is used to provide immediate relief and support rehabilitation efforts after disasters. The amount allocated to each state is decided by the Finance Commission, based on the state's disaster related spending over the previous ten years. The central government contributes 75 per cent of the fund, while the state government provides the remaining 25 per cent. Assistance to disaster affected populations is disbursed through this fund. While general guidelines for relief are framed at the national level, states may adopt their own specific norms through committees led by the Chief

Secretary. If the severity of a disaster exceeds the resources available under the CRF, additional financial support can be sought from the National Calamity Contingency Fund (NCCF).

National Calamity Contingency Fund (NCCF): It is a fund implemented at the national government level. When such requests are received, a central government team evaluates the requirements, and a high level committee led by the Deputy Prime Minister then approves the requirements.

6.1.3. Challenges in Disaster Management

Since the implementation of the Disaster Management Act, 2005 in India, notable achievements have been made across various aspects of disaster management, including prevention, preparedness, mitigation, response, and rehabilitation. However, significant challenges persist in the pursuit of disaster risk reduction. The following are some of the key challenges in disaster management in India:

Comprehending Disaster Risk: Disaster risk management needs to be based on a comprehensive understanding of disaster risks, which includes every aspect of hazard, vulnerability, exposure, and capacity. This knowledge is crucial for risk assessment, prevention, mitigation, and response. Disaster risks remain a difficulty for the nation regarding the implementation of disaster risk governance at the grassroots level.

Lack of Disaster Resilient Infrastructure: One of the major challenges in disaster management in India is the lack of strong and disaster resistant infrastructure. Essential services like electricity, communication, roads, and transport systems are often badly affected during disasters. Many cities and towns have weak buildings and poor planning, which makes them vulnerable to earthquakes, floods, and cyclones. In urban areas, poor drainage systems make flooding worse, leading to severe water logging and damage. These problems show the urgent need to build stronger, disaster-resilient infrastructure to reduce losses and improve safety.

Challenges in Coordination among Institutions: Another major issue is weak coordination between different disaster management agencies. Bodies like the NDMA,

SDMA, and DDMA are all involved in disaster response, but sometimes there are communication gaps and confusion about responsibilities. Effective disaster management also requires good cooperation between government agencies and NGOs. India's large and diverse population, with different needs in different regions, makes coordination even more challenging. Clear roles, better communication, and stronger cooperation are essential to improve disaster response.

Lack of Community Awareness and Participation: Public awareness regarding about preparedness is still low, especially in rural and economically weaker areas. Many people are not aware of evacuation procedures, first aid, or emergency response measures. Local communities are most of the time not fully involved in disaster risk reduction planning. Increasing community participation, spreading awareness, and strengthening early warning systems with timely communication are crucial for reducing disaster risks.

Early Warning Systems: The absence of effective early warning systems for different hazards defines a major challenge in disaster management. Despite significant investments in development, numerous regions, particularly remote and rural areas, continue to lack sufficient mechanisms for alerting communities regarding impending disasters. In various parts of the country, the development and implementation of early warning systems are ongoing, leading to delays in the dissemination of critical information. This gap increases vulnerability, restricts preparedness, and elevates the risk of loss of lives and property in emergencies. Enhancing early warning systems and facilitating prompt and extensive communication are essential for effective disaster risk reduction.

Challenges in Relief and Rehabilitation initiatives: After a disaster occurs, relief and rehabilitation efforts often face delays and inefficiencies. Resettlement of affected people can take a long time. Corruption and poor management sometimes delay the distribution of relief funds and essential supplies, making the situation worse for victims. Psychological and social support for survivors is also often neglected, even though it is very important for recovery. To improve this, there must be transparent

governance, proper use of resources, and a more comprehensive approach that includes both physical and emotional rehabilitation.

6.2. Disaster Management in Mokokchung District, Nagaland

Nagaland employs an integrated and comprehensive approach in terms of Disaster management and crisis response. With support from the Government of India and the United Nations Development Programme's Disaster Risk Reduction Project, the Nagaland State Disaster Management Authority (NSDMA) was established in January 2011. Thereby, to establish a disaster management institution with the state, a State Project Officer was appointed and assigned to the NSDMA Secretariat to establish a dedicated disaster management institution within the state. With the assistance of GoI-UNDP, the Nagaland State Disaster Management Authority (NSDMA) established its organizational structure by hiring additional personnel on contract.

6.2.1. Organizational Structure

Currently, the NSDMA secretariat is headed by the Home Commissioner who serves as Chief Executive Officer and a Secretary at the administrative level. The State Project Officer supervises the Program and Establishment Unit, with the assistance of an Accounts Officer. Initially at the district level, four District Project Officers (DPOs) were appointed to assist the District Disaster Management Authorities (DDMAs) in the districts of Kohima, Mokokchung, Dimapur, and Peren. Each district in Nagaland has progressively formed its own District Disaster Management Authority (DDMA), promoting relevant disaster management techniques. At the district level, the District Disaster Management Authority (DDMA) is headed by the Deputy Commissioner as the Chairman along with a District Disaster Management Officer (DDMO) and a District Project Associate (DPA) for each district.

Nagaland Disaster Management Plan (NDMP): Introduced in 2012, the Nagaland Disaster Management Plan (NDMP) implements a holistic and practical approach in addressing disasters. It has been implemented to address all kinds of emergencies by emphasizing the use of native resources, including local knowledge, manpower and

materials, to facilitate a cost effective and quick response to disasters. One of the key aspects of this plan is the engagement of traditional representative bodies, including councils and tribal unions, to enhance community participation. These groups/bodies play a major role in mobilizing people and resources during the time of crisis. Proper information is crucial for effective planning. Likewise, the plan emphasizes on creating information repositories at different administrative levels from the top down to the grassroot level inorder to enhance post disaster planning and resource exchange. The NDMP incorporates the following objectives:

- i. To identify and assess the state's vulnerability to various natural and human made disasters.
- ii. To develop suitable disaster prevention and mitigation strategies.
- iii. To formulate policies and guidelines that clearly outlines the roles and responsibilities of all stakeholders.
- iv. To reinforce the capacity of government bodies, voluntary organizations, and communities to effectively respond during disasters.
- v. To establish a well structured management information system that can support effective disaster response.
- vi. To incorporate and promote indigenous knowledge and traditional practices in disaster prevention and mitigation efforts.
- vii. To integrate capacity building and skill development as core components of the State's disaster management strategy.
- viii. To ensure adequate investment of funds and resources for the sustainability and success of the plan.
- ix. To encourage community involvement in both the planning and implementation of disaster management initiatives.
- x. To strengthen disaster management efforts through appropriate legislative and legal frameworks.

To minimize the loss of life, damage to property and disruptions to the social and economic activities of communities, the Nagaland State Disaster Management Plan emphasizes the importance of implementing targeted strategies across all phases of a disaster. These phases include the pre disaster phase, which focuses on

preparedness and risk reduction; the impact phase, including immediate response measures, and the post disaster phase which addresses recovery, rehabilitation, and reconstruction efforts. During the pre disaster phase, emphasizes are made on risk reduction, disaster preparedness and disaster mitigation activities. The key components of risk reduction activities include the following:

- i. Initiating measures to avoid technological instructions to reduce and eliminate natural hazards.
- ii. Developing and using technological interventions to reduce and eliminate natural hazards.
- iii. Developing hazard resistant structures.
- iv. Developing a strategy of preparedness at all levels of response to enable quick recovery from any disaster situation.

Disaster preparedness refers to the process of developing effective response plans to potential disaster threats. This includes estimating emergency needs and identifying resources required to meet those needs. The primary aim is to equip the local communities and stakeholders to respond effectively in the event of a disaster. Key measures in disaster preparedness include:

- i. Capacity building of individuals at all levels to enhance their ability to respond effectively during a crisis.
- ii. Formulating and enhancing targeted response plans to efficiently manage the specific challenges and needs at the village level. This also applies to each wards and colonies under municipal and town Committees inorder to ensure a comprehensive and multifaceted approach to any disaster threat.
- iii. Development of district level response plans within a standardized framework to enhance coordination and efficiency in disaster response effects.
- iv. Putting together an updated inventory of existing infrastructure and resources at every level of engagement, reflected in the district plans.
- v. Establishing community friendly warning mechanisms that are easy to understand and respond to by local residents, thereby enhancing public safety and emergency preparedness.

- vi. Spreading awareness is an important part of disaster management. This can be done through media campaigns, seminars, workshops, and by including disaster related topics in school and college curricula.

The Nagaland State Disaster Management Plan emphasizes the crucial role of disaster mitigation strategies within the state's overall pre disaster planning framework. Disaster mitigation aims to address the root cause of disasters by targeting and reducing the underlying hazards present in the local environment. The goal is to eliminate these risks or minimize their potential impact. Disaster mitigation measures include the following:

- i. Ensure strict adherence to established building codes and municipal by laws.
- ii. Conduct surveys to identify and evaluate building and structures which pose a potential risk.
- iii. Reinforce infrastructure in disaster prone areas to improve resilience against potential hazards.
- iv. Implementing micro zonation studies within districts to facilitate the creation of tailored and location specific disaster response plans.
- v. Engaging local communities by incorporating indigenous and traditional knowledge in hazard mitigation efforts.
- vi. Conducting thorough risk and vulnerability assessments at the district level through qualified and recognized agencies.
- vii. Promote research and development initiatives and reinforcing the transfer of appropriate technologies that corresponds the local environment and cultural context.
- viii. Design and implement targeted vulnerability reduction programs for high risk populations, particularly in remote and interior districts of the state.
- ix. Encourage coordination and partnerships among local governments, community based organizations, Non-governmental Organizations (NGOs), and other stakeholders to co-develop and strengthen mitigation strategies at all levels.
- x. Regulating land use practices to prevent construction in high risk areas.

- xi. Ensuring that new buildings and infrastructure are built in safe, risk informed locations.
- xii. Creating evaluation systems within disaster response plans, such as regular surveys, reports, and review meetings at district and state levels.

Post disaster activities primarily focus on the recovery phase, which involves providing assistance to individuals and communities affected by emergencies. The goal is to help affected individuals and communities return to normal life. Recovery is generally divided into short term and long term activities.

Short Term Recovery activities include:

- i. Restoring essential services like water supply, electricity, healthcare, and communication.
- ii. Rebuilding damaged infrastructure, homes, and buildings.
- iii. Conducting damage assessments of infrastructure and the region's economic and productive sectors.
- iv. Providing specialized support to meet the financial, social, and psychological needs of individuals, families, and communities.

Long Term Recovery activities include:

- i. Assessing the effectiveness of the Disaster Management Plan.
- ii. Reviewing the effectiveness of the Disaster management Plan.
- iii. Reassessing and reviewing mitigation strategies based on the impact and lessons learned.

Disaster Response Plan:

The State response plan provides a general framework to help officials, departments, and assisting organizations like coordinate their actions during a disaster. It outlines responsibilities and sets protocols for emergencies ranging from natural calamities to acts of terrorism. The plan includes:

- i. Specific procedures for responding to, mitigating and recovering from crisis.

- ii. Clear definition of the chain of command during emergencies.
- iii. A comprehensive communication plan to ensure accurate and timely information sharing among government bodies, NGOs, and communities.

6.2.2. District Disaster Management Authority (DDMA)

In recognition of its fundamental role in disaster risk reduction and emergency response, the district administration has created a comprehensive Disaster Mitigation Plan. The District Disaster Management Authority (DDMA) has been established as the primary coordinating entity to efficiently execute and manage this plan. The DDMA is the main authority responsible for disaster management at the district level. It consists of 19 members, and the Deputy Commissioner serves as the Chairperson.

The composition of the DDMA reflects an integrated, multi-stakeholder approach, incorporating heads of key governmental departments, representatives from the armed forces and paramilitary units, as well as members of non-governmental organizations (NGOs). This body represents the primary human resource base for disaster management activities within the district. As the most critical decision making entity in terms of disaster, the DDMA is entrusted with the dual responsibility formulating mitigation strategies and executing immediate response actions during emergencies.

To ensure a coordinated and effective response, the DDMA is assisted by many functional subcommittees, which are mobilized during occurrences of disaster. The subcommittees consist of members from the DDMA and are assigned specific operational responsibilities according to the nature and constraints of the disaster.

Furthermore, in order to strengthen disaster management capabilities at lower administrative levels, Sub-Divisional Disaster Management Authorities (SDDMAs) and Village Disaster Management Authorities (VDMAs) have also been established. These subordinate authorities operate in close coordination with the DDMA and function under its overall guidance and supervision. These tiered institutions together

constitute a decentralized and integrated disaster management framework designed to ensure timely and effective response across all levels of the district administration.

6.2.3. District Disaster Management Plan (DDMP)

The District Disaster Management Plan (DDMP) of Mokokchung is an extensive framework established by the District Disaster Management Authority (DDMA) to improve disaster preparedness, mitigation, response, and recovery initiatives within the district. It delineates the institutional framework and protocols essential for efficient disaster management. The DDMP functions as a dynamic document, undergoing regular reviews and revisions to integrate insights gained from previous occurrences and advancing best practices in disaster management. It highlights a multi-stakeholder strategy, engaging governmental bodies, community organizations, and the public to enhance resilience to disasters. Below is an overview of the key components and strategies outlined in the plan:

Objectives:

1. To improve district level preparedness by conducting risk and vulnerability assessments, which help reduce losses during disasters.
2. To review and assess the availability of resources and facilities of different agencies involved in disaster management, thereby strengthening the district administration.
3. To enhance disaster preparedness, build public confidence, and support the long term development of the district.
4. To create a system for documenting future disasters, updating important planning information, reviewing response actions, and recommending better strategies.
5. To establish the PDDMAP (District Disaster Management Plan) as an effective management tool within the policy framework of the Government of Nagaland.

Hazard, Vulnerability and Risk Assessment

The plan identifies by hazards and calamities district, including floods, cloudbursts, landslides, earthquakes and other hazards arising from human induced activities.

General Preparedness Measures

1. Control rooms have been established at both district and block levels with the support of concerned departments. These control rooms act as coordination centers during disasters. They help in sharing information quickly, issuing warnings, and ensuring a timely response.
2. The District Disaster Management Plan (DDMP) is regularly updated. It includes the latest information about trained personnel, contact numbers, available equipment, medical supplies, essential items, and vulnerable areas such as flood prone villages. Regular updates are important to ensure accuracy and preparedness.
3. Special training is given to search and rescue teams, first aid teams, and disaster management teams at village, block, and district levels. Since normal communication systems often fail during disasters, wireless communication facilities have been installed in Sub-Division and block offices. This helps in sending warnings and maintaining coordination during emergencies
4. Disaster Management Teams, made up of both male and female volunteers, are assigned specific roles such as rescue operations and first aid. They receive regular training to improve their skills and readiness.
5. Under the National School Safety Programme, selected individuals are trained as master trainers and trainers of trainers. This helps in spreading disaster awareness and preparedness in schools and educational institutions.
6. Mock drills are regularly conducted to put disaster management plans into practice. These drills improve community awareness and ensure that people are ready to respond quickly and effectively during real disasters.

6.2.4. Disaster Management measures

In order for a coordinated and effective management during crisis, various teams have been assigned specific roles across three phases of disaster management: Pre-disaster (preparedness and mitigation), during disaster (response), and post-disaster (recovery and rehabilitation). In addition to central teams, task specific teams have been constituted to enhance hazard mitigation efforts. Disaster management encompasses planning, preparedness, rescue, relief, and rehabilitation, all of which are addressed by the DDMA. Among these, rescue, relief and rehabilitation are highly task oriented and demand clear role allocation and efficient task management. To ensure effective and timely response, task specific committees have been formed, comprising members from the DDMA as per the Incident Response System and tailored to local conditions and resources.

Pre-Disaster Phase (Preparedness and Mitigation)

1. Early warning and Communication Team:
 - i. Monitor meteorological updates and issues timely alerts.
 - ii. Coordinate with IMD and relevant agencies for weather and hazard warnings.
 - iii. Disseminate warnings through control rooms, wireless systems, and community volunteers.
2. Planning and Coordination Team:
 - i. Update the District Disaster Management Plan
 - ii. Conduct risk and vulnerability assessments.
 - iii. Coordinate with various departments and stakeholders for mitigation planning.
3. Capacity building and Training Team:
 - i. Organize training for Disaster Management team at district, block, and village levels.
 - ii. Conduct mock drills, awareness programs, and community education.
4. Infrastructure and resource team:

- i. Identify and maintain critical infrastructure (roads, bridges, shelters).
 - ii. Prepare inventory of equipments, vehicles and emergency stock.
5. School Safety team:
- i. Implement the National School Safety Programme.
 - ii. Train teachers and students in basic disaster response.

During Disaster Phase (Response)

1. Search and Rescue Team:
 - i. Carry out evacuation and rescue operation in affected areas.
 - ii. Coordinate with NDRF/SDRF if deployed.
2. First Aid and Medical Team:
 - i. Provide immediate medical care to the injured.
 - ii. Set up temporary medical camps and coordinate with locals.
3. Relief and Management Team:
 - i. Manage relief camps and provide food, water and sanitation.
 - ii. Maintain order and basic services in shelters.
4. Traffic and Law and Order Team (Police/Administration):
 - i. Maintain law and order.
 - ii. Facilitate safe evacuation routes and secure affected areas.
5. Utilities and Infrastructure Restoration Team:
 - i. Restore electricity, water supply, and communication lines.
 - ii. Coordinate with PWD, Power and telecom departments.
6. Logistics and resource Mobilization team:
 - i. Mobilize and distribute relief materials efficiently.
 - ii. Maintain records of inventory and ensure equitable distribution.

Post-Disaster Phase (Recovery and Rehabilitation)

1. Damage Assessment team:
 - i. Assess losses to life, property, crops and infrastructure.
 - ii. Submit reports for compensation and reconstruction planning.
2. Health and Sanitation Team:
 - i. Prevent outbreaks of disaster through public health monitoring.
 - ii. Ensure sanitation in relief camps and affected areas.

3. Reconstruction and Rehabilitation Team:
 - i. Plan and implement long term rebuilding efforts.
 - ii. Engage with line departments and NGOs for livelihood restoration.
4. Psycho-social Support team:
 - i. Provide Counseling and mental health support to victims.
 - ii. Focus on vulnerable groups including women, children, and the elderly.
5. Monitoring and Evaluation Team:
 - i. Review the effectiveness of disaster response.
 - ii. Recommend improvements for future disaster preparedness.

6.2.5. Problems and Shortcomings of Disaster Management in Mokokchung District

Lack of Technological Integration: Mokokchung district faces major challenges due to limited access to modern technologies such as GIS, remote sensing, and drone surveillance. This makes it difficult to accurately map risks, assess damage, and monitor disaster prone areas. As a result, forecasting and real time response planning are weak. There is also no centralized digital platform to store and share disaster related data. Poor internet and mobile connectivity in rural areas further affects communication and coordination. In addition, many local officials and community workers lack technical training to use and maintain equipment, leading to inefficiency.

Data gaps and poor risk mapping: There is limited real time weather and seismic data available at the district level. This makes it harder to predict and monitor disasters. Risk maps showing landslide-prone areas, flood zones, and vulnerable infrastructure are often outdated or unavailable, increasing the district's vulnerability. This data gaps significantly implies planning and response efforts, leaving communities vulnerable and unprepared.

Geographical and environmental challenges: Mokokchung district lies in the highly Seismic Zone V, rendering it extremely vulnerable to earthquakes. Unfortunately, most buildings, including residential and public structures, lack structures-resistant design. Furthermore, the region is prone to frequent landslides during the monsoon

season, often triggered by deforestation, road construction, and unsustainable agricultural practices that destabilize the soil. Climate change has worsened these issues leading to more erratic rainfall and severe weather patterns, further increasing the district's vulnerability to disasters.

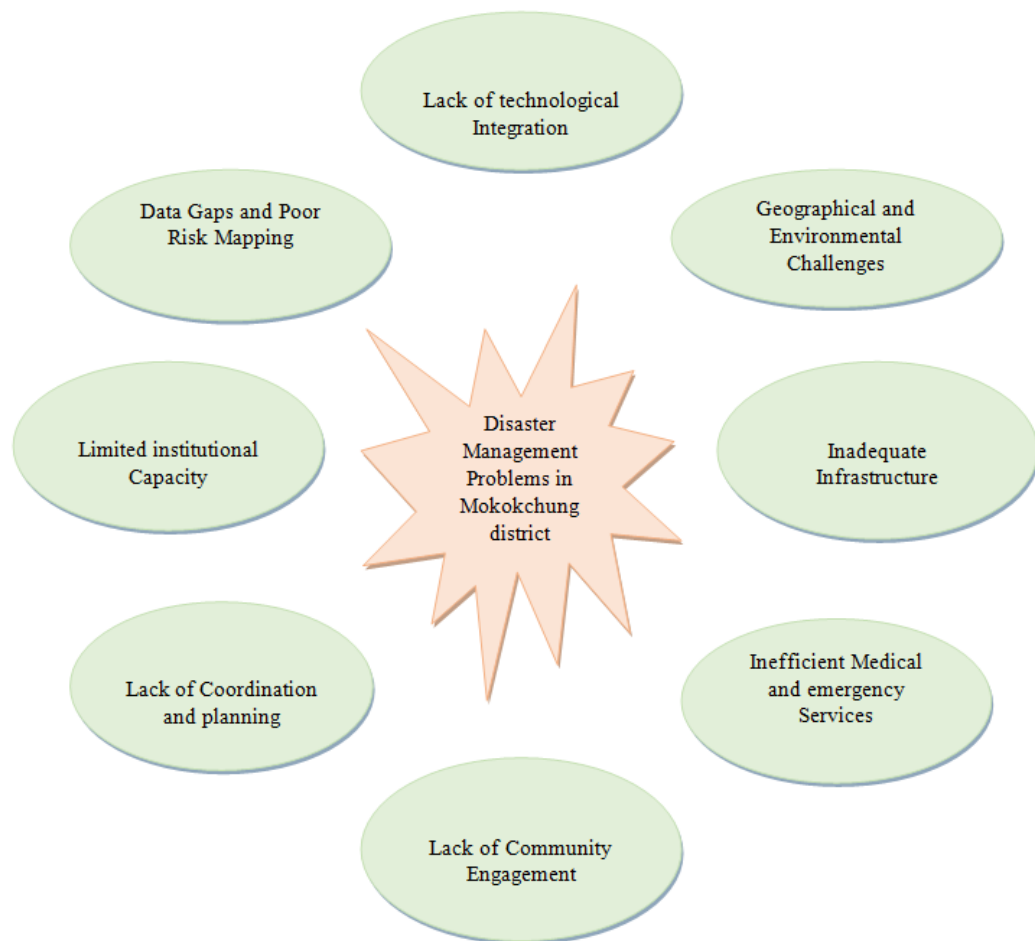


Figure 6.1: Disaster Management problems in Mokokchung District.

Inadequate Infrastructure: Weak infrastructure is a serious issue in the district. Many villages are connected by narrow, steep, and unpaved roads that often get blocked during heavy rainfall. This delays relief and rescue operations. Frequent power cuts and fragile water supply systems which depend on gravity fed springs further increase vulnerability. These systems can easily be damaged or contaminated during disasters, making emergency response more difficult.

Limited institutional capacity: The District Disaster Management Authority (DDMA) faces shortages of staff and funds. Budget limitations prevent proper implementation of disaster risk reduction programs, purchase of emergency supplies, and regular mock drills. As a result, disaster response is often reactive rather than well-planned and proactive.

Lack of coordination and planning: Disaster response efforts suffer due to poor coordination among government departments, police, fire services, health officials, local authorities, and community leaders. Although contingency plans exist, they are not always properly implemented. Mock drills, emergency stock maintenance, and volunteer training are often neglected.

Insufficient medical and emergency services: Healthcare facilities in rural areas are often understaffed and poorly equipped. Primary health centres and sub-centres struggle to handle emergencies during disasters. Fire and ambulance services are mostly located in the district headquarters, making it difficult to reach remote villages quickly.

Lack of community engagement: Community involvement in disaster management is very limited. Authorities often follow a top-down approach without actively involving local communities. As a result, people remain unaware and unprepared. Relief efforts may lack coordination, and grassroots training programs are rare. Although national policies emphasize community participation, it is not effectively practiced in the district, which weakens long term resilience.

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**STRATEGIES FOR MITIGATION AND MANAGEMENT OF
GEOMORPHOLOGICAL HAZARDS IN MOKOKCHUNG
DISTRICT**

Natural hazards are an inherent part of the earth's dynamic systems. However, the scale of their impact on human lives, infrastructure, and ecosystems is largely shaped by how prepared and informed societies are. While events such as landslides, flash floods, and earthquakes cannot be prevented, their destructive consequences can be significantly reduced through proactive planning, scientific assessment, and integrated mitigation strategies. In the context of accelerating climate change, rapid and unplanned urbanization, deforestation, and unsustainable land-use practices, the urgency of adopting comprehensive hazard management approaches has never been greater.

In many regions, the growing frequency and intensity of geomorphological hazards have been linked to human induced environmental change. Expanding settlements due to population pressure and limited availability of land have increasingly encroached upon hazard prone areas. In this process, vulnerability to hazards is considerably increased. In Mokokchung, as in many parts of India, these patterns demand urgent intervention to improve risk assessment, mitigation planning, and adaptive infrastructure development. The limited availability of suitable land for construction in steep, undulating landscapes makes large scale relocation of hazard prone communities which are impractical in most cases. As a result, alternative approaches must be prioritized. Temporary evacuations during high risk periods, alongside resilient in place adaptation strategies, offer more realistic and context sensitive solutions. Strengthening slope stabilization measures, improving drainage systems, enforcing building codes, and enhancing early warning systems can collectively reduce exposure and vulnerability without necessitating displacement. Ultimately, building resilience in Mokokchung requires more than structural interventions. It requires empowering communities with knowledge, preparedness

training, and participatory planning mechanisms that enable them to coexist with natural hazards. By fostering adaptive capacity and ensuring that development aligns with the region's environmental realities, it is possible to maintain functionality during disruptive events while safeguarding long term sustainability. As hazard risks intensify under changing climatic conditions, region specific, scientifically grounded strategies will be essential to protect lives and promote resilient development pathways.

7.1. Strategic Approaches to Landslide Risk Reduction and Management

- i. Landslide Hazard Mapping:** Reducing landslide risk and ensuring sustainable development in vulnerable hilly regions requires reliable, scientifically grounded, and user friendly hazard maps that can be integrated into planning and policy frameworks. Landslide hazard mapping provides a systematic way to classify terrain into zones based on the probability and potential severity of landslide occurrences. Such mapping not only supports informed decision making but also enables authorities to regulate development in high-risk areas. As outlined by Singh and Parkash (2019), three interrelated forms of zoning are particularly important:
 - a. Landslide Susceptibility Zoning (LSZ):** This approach evaluates the likelihood of landslide occurrence by analyzing terrain characteristics and historical records. It considers factors such as geology, slope gradient, soil type, drainage patterns, vegetation cover, rainfall intensity, and anthropogenic interventions including road cutting, excavation, and deforestation. LSZ provides a foundational understanding of where landslides are most likely to occur.
 - b. Landslide Risk Zoning (LRZ):** Building upon susceptibility assessments, hazard zoning introduces a more quantitative dimension by estimating the probable frequency and magnitude of landslides within identified zones. This allows planners to distinguish between areas of occasional minor slope failure and those prone to recurrent or large scale events.
 - c. Landslide Risk Zoning (LRZ):** Risk zoning incorporates hazard data with exposure and vulnerability assessments. It accounts for elements at risk such as population density, housing, critical infrastructure, and economic assets

along with their capacity to withstand or recover from landslide events. This makes LRZ particularly valuable for administrators, urban planners, and disaster management authorities seeking to prioritize interventions.

The success of these zonation strategies depends on the use of advanced technologies like high resolution satellite imagery, UAV surveys, and GIS based spatial analysis. Tools such as Terrestrial Laser Scanners and remote sensing can significantly enhance the accuracy of these maps. Developing a district specific, scientifically validated landslide hazard mapping system for Mokokchung is not only technically feasible but also strategically urgent. By combining advanced mapping tools with local insights and institutional collaboration, Mokokchung district can enhance its resilience to landslides. Following steps are recommended for landside Hazard mapping of Mokokchung:

1. Compile and conduct comprehensive review of existing landslide studies and hazard assessments in Mokokchung and surrounding districts, and focusing on the mapping scales, techniques, and classification method used by agencies such as Geographical Survey of India, North Eastern Space Applications Centre and Nagaland GIS and Remote Sensing Centre in order to identify methodological gaps and inconsistencies specific to the region's terrain and hazard characteristics.
2. Draft mapping guidelines specific to the region's geological context including the impacts of road expansion, shifting cultivation and deforestation. Incorporate UAV based surveys, GIS, and high resolution earth observation data for precision at both macro and meso scales.
3. Generate cartographic representations of actual landslide occurrences in the region and estimate degrees of slope instability using established criteria to enhance the accuracy and reliability of the hazard zonation maps and integrating LHZ maps into the District Disaster Management Plan (DDMP), town planning regulations, and rural infrastructure codes.
4. Utilize hazard maps to regulate development, ensure compliance, and guide the design and implementation of infrastructure projects. Provide training for local

engineers, government officials, and community members to enable effective understanding and use of hazard maps.

5. Establish a monitoring system using remote sensing tools and ground sensors to track slope changes. Periodically update hazard maps and ensure that all development activities follow the zonation recommendations through oversight by local regulatory authorities.
6. Promote public awareness on slope stability, safe construction practices, and emergency preparedness.

ii. Landslide mitigation engineering strategies: According to the IUGS Working Group on Landslides (Popescu, 2001), landslide remedial measures can be classified into four practical categories:

- a. Altering the geometry of slope:** Modifying the slope profile through controlled cutting or filling is a widely applied technique, particularly in cases of deep seated landslides. By reducing slope angle or removing unstable material, the overall driving forces acting on the slope can be minimized. Careful attention must be given to critical slope features such as the neutral line and zones of maximum stress concentration when planning such interventions. Because slope modification directly alters the stability conditions, it is often implemented in combination with complementary measures like drainage or structural support. When properly designed and executed, this method remains one of the most cost effective long term stabilization strategies.
- b. Improving the conditions of drainage:** Excess pore water pressure is one of the most significant triggers of slope failure, particularly during periods of intense or prolonged rainfall. Improving surface and subsurface drainage is therefore a highly effective and economical mitigation approach. Common techniques include surface ditches to divert runoff, trench drains, sub-horizontal boreholes, deep drainage wells, and drainage tunnels. By facilitating controlled water discharge and reducing soil saturation, these systems enhance shear strength and overall slope stability.
- c. Constructing retaining structures:** In high risk zones or areas where land availability is constrained, engineered structural solutions provide critical

support. Retaining walls, passive piles, caissons, and ground anchors are commonly used to resist lateral earth pressures and stabilize unstable slopes. While these interventions can be resource intensive, they are particularly valuable in protecting infrastructure such as roads, buildings, and critical facilities situated along vulnerable hillsides.

- d. Reinforcing the slope internally:** Internal stabilization techniques focus on strengthening the slope mass without extensive surface alteration. Methods such as soil nailing, pressure grouting, and the installation of reinforcement elements enhance the internal cohesion and load bearing capacity of the soil. Biotechnical stabilization which involves using vegetation to bind soil and regulate moisture is an environmentally sustainable alternative. Vegetation contributes to slope stability by reinforcing the soil matrix with root systems and reducing water infiltration through evapotranspiration, although its effectiveness may vary depending on landslide depth and soil conditions. These approaches are mostly cost effective, eco-friendly, and minimize large scale disturbance to the natural landscape.

7.2. Sustainable Strategies for Soil Erosion Control and Land Conservation

Soil erosion is a major concern in Mokokchung due to its hilly terrain, heavy monsoonal rainfall, and widespread shifting cultivation (Jhum). Effective management combines traditional knowledge with modern conservation practices. Some of the major measures are:

- i. In Mokokchung where traditional Jhum practices are prevalent, adopting agro-forestry offers a balanced alternative that will support both livelihood and environmental conservation.
- ii. Contour farming is a practical and sustainable method for reducing surface runoff and soil erosion on sloping agricultural lands. By aligning ploughing and planting activities along the natural contours of the slope rather than up and down, the flow of water is slowed, allowing greater infiltration and reducing soil loss. This technique not only facilitates water retention but also helps maintain soil fertility over time. Importantly, it can be adapted to existing local farming practices, making it both environmentally sound and socially feasible.

- iii. In several villages of Mokokchung, particularly in the valleys and on lower hill slopes, terrace paddy cultivation is already in practice. However, many areas continue to depend heavily on shifting cultivation. Expanding terrace farming into other suitable locations could substantially reduce soil erosion by stabilizing slopes and regulating water flow. Well designed terraces not only minimize land degradation but also improve agricultural productivity and long term land sustainability.
- iv. The use of cover crops and mulching serves as another effective measure for conserving soil considering Mokokchung's fragile hilly terrain. These practices protect the soil surface from direct impact of rainfall, reduce runoff, and help retain moisture during dry periods. Incorporating leguminous cover crops is particularly beneficial, as they naturally fix atmospheric nitrogen, thereby improving soil fertility without excessive reliance on chemical fertilizers. Together, these measures support both environmental conservation and sustainable agricultural production.
- v. Shifting cultivation remains integral to the region's socio-cultural and economic fabric till date. Its sustainability can be improved by promoting longer fallow periods, allowing adequate time for natural soil regeneration. The integration of nitrogen fixing trees during fallow phases can further accelerate soil fertility restoration, reduce land degradation, and support more resilient agro-ecosystems.
- vi. Bioengineering approaches offer cost effective and ecologically sensitive solutions to soil erosion. The use of vegetation such as vetiver grass and bamboo hedges can effectively stabilize slopes and reduce runoff. These fast growing, deep rooted species bind the soil, enhance slope stability, and are particularly well suited to regions characterized by steep terrain and heavy rainfall. By combining traditional ecological knowledge with scientific land management practices, such measures can significantly strengthen landscape resilience while maintaining environmental integrity.

7.3. Strategic approaches to Flash Floods Mitigation

Flash flood mitigation measures can be broadly classified into structural and non-structural types. These two approaches are often complimentary, and an effective flash flood management strategy should ideally incorporate elements of both. Following are some of the strategic measures for mitigation of flash floods:

- i. Measures across all the catchment areas in order to slow down surface runoff and reduce erosion, which helps lower flash flood risks. These will include terracing, building stone walls, reinforcing slopes, and stabilizing small streams and drainage channels. Non-structural approaches like proper land-use planning also play a key role by controlling runoff and limiting flood impacts.
- ii. Regulating rivers and streams to manage water flow and reduce erosion by flattening slope and strengthening banks. Common methods include wooden or stone barriers, gabions, anti-debris dams and protective embankments.
- iii. Conservation of rivers by maintaining the natural depth and gradient of the riverbed to ensure smooth flow, preventing excessive sediment buildup, and safeguarding the valley's capacity to accommodate high discharge during intense rainfall events. Selective and strategic clearing of obstructive vegetation may also be necessary to maintain channel efficiency, while avoiding excessive alteration of the natural ecosystem. A balanced approach that respects both hydrological function and ecological integrity is essential for long term flood mitigation.
- iv. Rainfall induced flash floods are typically triggered by short duration and high intensity convective precipitation that can overwhelm drainage systems within a short span of time. To effectively respond to such events, real time monitoring of rainfall intensity and cumulative precipitation is crucial. This can be achieved through a combination of in-situ rain gauge measurements and advanced remote sensing technologies, including satellite based and radar based rainfall monitoring systems. Integrating these data sources enables timely warnings, improved forecasting accuracy, and more coordinated emergency responses.

- v. Addressing flash flood risks requires strong policy support and institutional coordination. Risk assessments and mitigation strategies should be formally integrated into Mokokchung's District Disaster Management Plan (DDMP), incorporating hazard mapping, early warning systems, evacuation protocols, and response mechanisms. Close coordination with agencies such as the Nagaland State Disaster Management Authority (NSDMA), Nagaland GIS and Remote Sensing Centre (NGISRSC), and the India Meteorological Department (IMD) is essential. Effective real time data sharing, accurate forecasting, and collaborative planning among these institutions will significantly strengthen disaster preparedness and response capacity in the district.

7.4. Preparedness and Risk Reduction Strategies for Seismic Hazards

Seismic Hazard Mapping: It is a vital approach for converting seismic hazard assessments into detailed spatial visualizations. Unlike zonation, which categorizes into distinct hazard classes, seismic mapping focuses on geographically visualizing these hazards at a detailed scale. Seismic mapping uses GIS, remote sensing and field data integration in order to illustrate how hazard zones intersect with settlements, infrastructure and key resources (Ansal, 2004; Rosa et al., 2008). These kinds of maps will not only help planners and engineers to find high risk areas and communities at risk but also help decision making bodies to prioritize where mitigation measures are most needed (Finn et al., 2004). For Mokokchung district specifically, seismic mapping can be helpful in identifying slope settlements at risk, transportation routes prone to earthquake disruption and river valleys susceptible not only to shaking but also to related secondary hazards.

Seismic Risk Assessment: It is a fundamental element of seismic mitigation planning as it helps communities in understanding the probability and potential consequences of earthquake events. This will enable the development of focused strategies to reduce risk and strengthen resilience. An effective risk assessment should focus on three interconnected components: (i) hazard analysis, which identifies earthquake prone areas and estimates the likelihood of future events, (ii) vulnerability analysis, which analyzes the susceptibility of infrastructure, lifelines and populations and (iii) risk mapping,

which visually depicts spatial differences in seismic risk to locate concentrated vulnerabilities. These combined components provide a structured approach for formulating effective mitigation measures and preparedness plans.

Policy and Planning for Seismic Resilience: Policy frameworks and urban planning are vital for embedding risk reduction into development processes. Governing bodies at all levels are crucial in fostering an environment conducive to resilience through the following key measures:

- i. Building codes and standards:** Ensuring that new buildings are constructed to withstand earthquakes by enforcing seismic resistant design and construction practices.
- ii. Land-use regulations:** Restricting development in high risk seismic zones and incorporating risk considerations into urban growth planning in order to prevent unsafe expansion.
- iii. Financial incentives:** Implementing financial support mechanisms such as subsidies, grants and low interest loans to encourage property owners to retrofit existing structure and adopt earthquake resistant building practices.
- iv. Public awareness campaigns:** Conducting comprehensive public awareness about earthquake risks and promoting preparedness at the household and community levels.

7.5. SWOT Analysis of Disaster Management in Mokokchung District

SWOT analysis is a widely applied strategic planning tool used to assess an organization's internal and external environment to support decision making and long term planning. Similar to other analytical frameworks, it helps to identify key issues that influence performance by categorizing them into four categories: strengths, weaknesses, opportunities and threats. Strengths and weaknesses represent the internal characteristics of an organization such as resources, capabilities and operational structure, while opportunities and threats refer to the external conditions including policy changes and external risks that could negatively impact the organization. By systematically evaluating these factors, SWOT analysis improves comprehensive awareness of the strategic environment by systematically evaluating these aspects

which enable organizations to plan more efficiently and reduce risks before they intensify.

A SWOT analysis of Mokokchung District has been done (Figure 7.1) by integrating a review of existing policies and secondary data, supported by field observations. It presents a structured evaluation of disaster management practices in Mokokchung district, guiding future strategies aimed at reducing risks and enhancing resilience.



Figure 7.1: SWOT Analysis of Disaster Management Practices in Mokokchung District.

Strengths

- i. **Institutional frameworks in place:** A key strength of disaster management in Mokokchung is the robust institutional framework that structure that supports a structured and decentralized approach to disaster risk reduction. The Nagaland State Disaster Management Authority (NSDMA) provides overall coordination, while the State and District Disaster Management Authorities (SDDMA & DDMA) handle localized planning and response. The DDMA operates through specialized sub-committees focusing on key functions such as early warning, relief, and health.
- ii. **Integration of traditional institutions:** Integrating traditional institutions into disaster management processes significantly strengthens community resilience. In Mokokchung, tribal councils, student bodies, and local governance institutions play an important role in mobilizing resources, disseminating information, and ensuring that response strategies are culturally appropriate and locally accepted. Their grassroots engagement enhances trust, improves coordination during emergencies, and supports more effective disaster response.
- iii. **Comprehensive disaster management planning system:** A comprehensive disaster management planning system further reinforces these efforts. The National Disaster Management Plan (NDMP) and the District Disaster Management Plan (DDMP) provide a holistic framework that addresses preparedness, mitigation, response, and recovery. By incorporating indigenous knowledge and locally adapted risk reduction practices, these plans become more context sensitive and sustainable.
- iv. **Capacity building and training initiatives:** Regular mock drills, public awareness campaigns, and structured community training programs improve preparedness across all stakeholder groups. Initiatives such as the School Safety Program and master trainer programs ensure that educational institutions and local leaders are equipped to respond promptly and effectively during emergencies.
- v. **Decentralized control rooms and communication systems:** Establishing decentralized control rooms at the block level enhance real time decision making

and coordination. Complementing this with wireless communication systems ensures that early warnings can be disseminated and communication maintained even when conventional networks are disrupted, thereby strengthening overall disaster response capacity.

Weaknesses

- i. Lack of technological integration:** One of the major weaknesses in strengthening disaster management in Mokokchung is the limited integration of modern technologies. The district makes minimal use of tools such as GIS, remote sensing, drones, and real time data platforms, which reduces the efficiency of early warning systems and hazard monitoring. In addition, the absence of a centralized digital infrastructure restricts timely data sharing and coordination among relevant agencies, often slowing decision making during critical situations.
- ii. Inadequate risk mapping and existing data:** Another major weakness is the inadequacy of reliable and up to date risk mapping data. The lack of real time meteorological, seismic, and hazard zonation information limits accurate risk assessment and preparedness planning. Without consistent and scientifically validated datasets, disaster management efforts tend to remain reactive thereby responding to events after they occur rather than proactive and preventive in nature.
- iii. Limited Institutional Capacity and Resources:** Shortages in staffing and funding restrict the district's ability to fully implement disaster management plans. Inventories, drills, and emergency exercises are often insufficient or irregular, weakening preparedness across all levels.
- iv. Weak level of community engagement:** Local communities are frequently excluded from planning and decision making, resulting in a top down approach that reduces public awareness and ownership of risk reduction efforts. While traditional institutions play a crucial role in mobilizing communities during disasters, their participation is often informal and reactive, leaving a gap between formal institutional frameworks and grassroots engagement.

- v. **Lack of adequate psychological and social support services:** Post-disaster mental health needs are often unmet due to limited counseling and psychological support services. Trauma, stress, and anxiety go largely unaddressed, especially among vulnerable populations, which hamper recovery and reduce community resilience to future disasters.

Opportunities

- i. **Technological upgrades and digital platforms:** Strengthening disaster risk management in Mokokchung requires a gradual but meaningful integration of modern technology. Tools such as GIS mapping can help clearly identify hazard prone zones, enabling authorities to design targeted mitigation strategies. Drone surveys are particularly useful in hilly and inaccessible terrain, allowing rapid damage assessment and improving the speed and accuracy of response. In addition, real time monitoring systems such as rainfall gauges, river level sensors, and seismic instruments can enhance early warning mechanisms, making timely evacuation and dynamic risk assessment possible.
- ii. **Scope for research and development:** There is also considerable scope for focused research and development suitable for Mokokchung's unique geography and socio-cultural context. Academic institutions and technical experts can examine local hazard patterns, traditional coping mechanisms, and patterns of vulnerability within communities. Such research can inform the design of low cost, disaster resilient infrastructure and context specific mitigation strategies that are both practical and sustainable.
- iii. **Public-private and NGO partnerships:** Partnerships with non-governmental organizations, private technology firms, and civil society groups can further strengthen institutional capacity. These collaborations can provide technical expertise, logistical assistance, and financial support, while also contributing to community training and awareness programs. By complementing government efforts, such partnerships help bridge gaps in implementation and enhance resilience at multiple levels.
- iv. **Community-based structures and participation:** Establishing village-level disaster management committees composed of local leaders and volunteers can

ensure that grassroots initiatives align with district level strategies. These bodies serve as essential channels for communication, feedback, and participatory planning, fostering a sense of shared responsibility.

- v. **Joint capacity building and simulation Drills:** Regular joint training programs and simulation drills involving both district authorities and village representatives are vital for improving coordination and operational readiness. Such exercises strengthen skills in search and rescue, first aid, and emergency response, while periodic evaluations help refine and update response protocols.
- vi. **Integration of technology:** Integrating user friendly digital tools such as mobile applications and district level dashboards can streamline alert dissemination and incident reporting. Predictive analytics can assist in identifying emerging risks and preparing in advance. However, for these technological measures to be sustainable, they must be supported by clear policies, dedicated district level technical units, and continuous institutional commitment.

Threats

- i. **Environmental and Geophysical hazards:** Located in the high seismic Zone V, Mokokchung district of Nagaland is highly prone to earthquakes, landslides and slope instability. Seasonal floods caused by intense rainfall, compounded by deforestation and slope modification, worsen the risks. The increasing unpredictability of weather patterns ranging from intense rainfalls to prolonged dry spells is a direct result of climate change. These erratic environmental shifts not only trigger disasters but also affect agriculture, water availability, and soil health, intensifying the district's vulnerability to hazards.
- ii. **Socio-economic fragility:** The district's socio-economic profile adds another layer of vulnerability. A large proportion of the population is engaged in subsistence farming and informal labor, which hawks resilience to disaster induced shocks. Many homes, especially in rural and semi urban settlements, are built without adherence to safety codes, making them structurally unsafe in seismic or other hazard prone areas. Additionally, traditional beliefs and resistance to modern approaches can limit the adoption of scientifically informed disaster mitigation strategies.

- iii. **Dependence on external agencies:** The district's response capacity remains heavily reliant on external aid from state level agencies, NGOs and military units. While external support is crucial during large scale disasters, over dependence without local capacity development poses long-term risks. During widespread emergencies, these agencies may be stretched thin, causing delays in response. A locally driven, decentralized preparedness strategy is essential for timely and context specific interventions.
- iv. **Environmental degradation and urban pressures:** Encroachment on forest lands, improper waste disposal, and unsustainable land use has worsened environmental risks. Urban growth in Mokokchung has often occurred without adequate environmental planning, increasing the risk of flash flooding and drainage congestions. Degraded landscapes reduce the effectiveness of nature based buffers such as wetlands and forest cover.
- v. **Financial mismanagement and relief distribution challenges:** Relief and rehabilitation efforts often suffer from insufficient fund management. Delays in disbursements, poor oversight mechanisms, and limited transparency have occasionally led to resource misallocations, reports of fund diversion, redundancy in relief efforts, and a lack of real-time monitoring are not uncommon. This not only diminishes trust among affected communities but also hampers long term recovery.

The SWOT analysis of disaster management in Mokokchung district reveals a limited but valuable set of strengths that contribute to the region's capacity to respond to disasters. However, these strengths are overshadowed by more significant weakness, opportunities, and threats that the district continues to face in the disaster management efforts. Key elements such as risk assessment, community training, early warning systems, and resilient infrastructure are either poorly developed or entirely lacking. Despite the challenges, the district also holds opportunities for strengthening its disaster resilience. If leveraged properly, these opportunities can significantly enhance preparedness and reduce long-term vulnerability. The SWOT analysis emphasizes the urgent need to move beyond a relief centric approach, integrating preparedness, mitigation and rehabilitation into the core of disaster management. The

increasing vulnerability in Mokokchung district to disasters is compounded by economic, socio-political dynamics and ecological degradation, all of which hinder effective disaster management.

- 1. Economic constraint:** Mokokchung faces several challenges that complicate effective disaster management. One of the primary constraints is economic given that limited financial resources often delay relief operations, restrict access to emergency healthcare and education, and hinder long term rehabilitation. Repeated disasters further strain the district's modest economy, making it essential to prioritize the efficient use of available funds to ensure that even small investments yield meaningful results.
- 2. Socio-political and cultural challenges:** Socio-political and cultural factors also influence disaster response. While there are presence of strong community structures, their potential is mostly underutilized due to the weak coordination among administrative agencies, limited monitoring of relief distribution, and insufficient involvement of local NGOs and civil society. Issues such as mismanagement of funds, unaddressed psychological trauma among affected populations, and low community engagement underscore the need for inclusive, transparent governance that actively involves all stakeholders.
- 3. Ecological aspect:** The hilly terrain of Mokokchung is increasingly vulnerable to deforestation, unregulated road construction, and unsustainable land-use practices. These activities destabilize the environment and amplify the impact of disasters. Integrating eco-sensitive development policies with traditional knowledge is therefore critical to preserving natural defenses, reducing disaster risk, and promoting long-term sustainability.

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SUMMARY AND CONCLUSION

The present study focuses on the assessment of geomorphological hazards in Mokokchung district, which is a hilly and environmentally sensitive region of Nagaland in Northeast India. Mokokchung district covers an area of approximately 1,615 km² and is characterized by rugged terrain, steep slopes, deeply dissected landforms, and fragile geological conditions. Located in the tectonically active Indo-Myanmar arc, the district experiences continuous seismic activity and terrain instability making it vulnerable to natural hazards. Owing to the interaction between terrain, climate, and human activities, Mokokchung district represents a dynamic and hazard prone environment. Mokokchung experiences a humid subtropical to mild temperate climate depending on elevation, and receives most rainfall during the monsoon season from May to September. The region receives an average annual rainfall between 2000-2500 mm. However, recent climatic records show increasing variability, with more frequent and high intensity rainfall events and extended dry periods. These changing rainfall patterns intensify stress on the already weak hill slopes and gives rise to processes such as soil erosion, gully development, landslides and other forms of mass movements and flash floods in river valleys and foothills. From a geological perspective, Mokokchung district is mainly composed of tertiary sedimentary formations belonging to the Disang and Barail groups. These formations consist of alternating layers of sandstone, shale, and siltstone. Over time, these rocks have been weathered, fractured and weakened by tectonic folding, faulting, and shearing linked with past and ongoing tectonic activity in the region. The predominance of shale and other argillaceous rock units possessing relatively low material strength, when exposed to intense rainfall are highly susceptible to erosion and slope failure, particularly in areas where slope modification and land-use practices are inadequate. As a result, lithological conditions are an important factor in controlling slope instability across Mokokchung district. Geomorphologically, Mokokchung is characterized by steep hill slopes which exceeds 30°, and has narrow ridgelines, deeply incised river valleys, and fast flowing streams that drain into the

major rivers such as Dikhu and Milak. Elevation ranges from about 180 m in the valley bottoms to nearly 1800 m in the upland areas, resulting in varied landform zones with different levels of exposure and susceptibility to geomorphological hazards across the study area.

Land use and land cover analysis indicates significant human driven changes to terrain as well as vegetation across Mokokchung district. While dense forest cover persists in high elevation, inaccessible areas, much of the vegetation has been fragmented due to shifting cultivation, agricultural expansion and rapid growth of semi urban and urban areas. Built up areas continue to grow in and around Mokokchung which involves road construction, slope cutting, land filling, and the spread of hillside settlements further altering natural slope conditions and increasing instability. The transformation of forested slopes into agricultural terraces, roads, and exposed surfaces has weakened natural slope reinforcement. As a result, surface runoff and transport of sediments have increased; further intensifying erosion and the likelihood of slope failure. The demographic pattern of Mokokchung district shows an uneven distribution of population, with higher concentrations along administrative centers and road accessible corridors, and much lower densities in remote highland villages. The social and economic profile reflects a mixed livelihood system, where agriculture, wage labour, emerging service sector jobs, and small scale trading form the main sources of income. Despite this diversity, the dependence on natural resources remains quite high and levels of awareness regarding geological hazards and scientific land-use practices vary greatly different communities. The ongoing expansion and improvement of transport networks, especially the national and state highways, has improved connectivity within the district as well as the bordering areas. However, cutting of slopes and terrain modification for this purpose, without proper stabilization and drainage measures have increased exposure to hazards. The combined effects of fragile rocks, steep slopes, high intensity rainfall, and increasing human intervention has created conditions where hazards such as landslides, soil erosion, debris flows, land subsidence, and flash floods are becoming more severe and frequent. These processes are not only isolated events but part of an increasingly unstable landscape shaped by both natural forces and human interventions. The physical characteristics of

Mokokchung district, together with changing climatic patterns and growing development pressures, indicate Mokokchung as a geomorphologically sensitive region, wherein natural processes and human activities intersect to shape vulnerability. Similar patterns observed in Kohima and other hill districts indicate that the hazard conditions in Mokokchung district are part of a broader regional trend across the Indo-Myanmar hill systems where expanding settlements, infrastructure development, and climate driven hydrometeorological extremes are exerting great stress on existing fragile hill environments.

The present study identifies four major geomorphological hazards in Mokokchung district: landslides, soil erosion, flash floods, and seismic disturbances. Each of these hazards is shaped by a combination of natural terrain conditions and human-induced activities, and their spatial distribution reflecting the complex interaction between lithology, slope, land use and hydrology, and climatic variations. Landslides are the most widespread and recurrent hazard affecting the district. Weak lithology, concentrated rainfall, and unregulated land modification significantly contribute to slope failures. Landslide susceptibility mapping indicates particularly high hazard levels along road corridors, in village settlements located on steep ridge slopes, and in areas that have recently undergone land-use change. Road expansion and infrastructure developments play a major role in increasing risk of landslides. Extensive cutting of slopes and earth removal associated with these projects are often undertaken without sufficient engineering support or proper drainage systems, thereby destabilizing already fragile slopes. Observations made during field survey reveal that many of the landslides are shallow transitional failures, primarily triggered by rainfall induced infiltration that increases pore-water pressure and reduces slope stability. In several locations, the reactivation of older landslide scars during monsoon season indicates to ongoing slope adjustment processes and the need continuous hazard monitoring and targeted mitigation measures. Soil erosion is another major geomorphic hazard affecting Mokokchung district. Intense rainfall, highly erodible shale-dominated lithology, exposed hill slopes, shifting cultivation and road construction has led to accelerated soil loss across the landscape. Erosion occurs through sheet erosion, rill and gully development, slope denudation, and the transport

of sediments into river systems. Areas most vulnerable to erosion include deforested slopes, agricultural terraces with limited vegetation, and roadside cuttings where loose materials remain exposed. As seen in other hill districts of Nagaland, soil erosion in Mokokchung is not only a geomorphic concern but also an ecological and socio-economic issue, contributing to declining soil fertility, reduced agricultural productivity, and increased sediment loads within river systems. Flash floods represent a more localized but increasingly emerging hazard, particularly in valley bottoms and foothill transition zones. Shifts in rainfall patterns toward shorter-duration but higher intensity rainfall events frequently overwhelm natural and artificial drainage systems, resulting in rapid surface runoff and sudden downstream surges. Settlements and agricultural lands located along low lying river terraces and floodplains are especially vulnerable to these events. Evidence from recent years show increasing debris flow activity associated with runoff concentration, slope saturation, and loose surface material mobilization from road cuttings and deforested areas. These impacts are further intensified by inadequate drainage planning and the expansion of built-up areas into natural flow pathways. Seismic hazards further increase the district's vulnerability because it lies in a tectonically active region. Although high magnitude earthquakes are relatively infrequent, recurring micro to moderate seismic tremors can destabilize already fragile slopes and alter local drainage conditions. When combined with periods of heavy rainfall, seismic activity increases the prospects of other related hazard processes such as delayed slope failures and ground fissuring. Similar patterns observed in Kohima and Wokha suggests that the combination of fine grained lithology and steep terrain significantly increases seismic hazard potential in Mokokchung.

The study shows that hazard vulnerability in Mokokchung is not evenly distributed. It is concentrated in areas influenced by topography, density of settlements, infrastructure development, and land-use practices. Urban and semi urban areas face increasing risks due to rapid expansion, slope modification, inadequate planning, and weak compliance with safety guidelines. Also, rural areas remain vulnerable to hazards because of dependence on land-based livelihoods and limited access to stabilization measures. Climate change is further intensifying the existing

fragile hazard environment. Increasing rainfall variability, rising temperatures, and more frequent extreme rainfall events place additional hydrological stress on slopes and drainage systems. As a result, geomorphic instability is becoming more widespread, especially in zones experiencing settlement growth and infrastructure expansions. The findings of this study shows that the interaction of geomorphic processes, climate forces, and human development patterns has created a hazard landscape that requires comprehensive monitoring, informed policy frameworks, and community driven resilience strategies. Hazards in Mokokchung are dynamic and interlinked rather than isolated occurrences, and as a result, their combined effects pose serious challenges to sustainable development and environmental stability. The assessment of geomorphological hazards in Mokokchung district reveals that the region is experiencing increased physical and environmental stress due to the interaction of natural terrain dynamics, climate variability, and human induced modifications. The district's fragile lithological framework, steep relief, high rainfall concentration, and ongoing seismic activity form the fundamental basis of hazard susceptibility.

Study of human geography further indicates that vulnerability in Mokokchung is closely linked to settlement patterns, socio-economic conditions, and the capacity of communities to adapt. Many of the settlements are located on steep ridge tops and unstable slopes, where existing local engineering measures are often insufficient to withstand extreme weather events. Traditional land-use systems, especially shifting cultivation (jhum), continue to influence slope stability by exposing large areas of soil to rainfall-induced erosion. At the same time, the expansion of road networks has improved connectivity and access but has also intensified slope instability in areas where proper engineering support and stabilization measures are still lacking. These patterns demonstrate that Mokokchung's geomorphic hazards are multidimensional and require integrated, place-specific approaches. Similar to trends observed across other hill districts of Nagaland and Northeast India, environmental degradation, unplanned development, and climate-driven hydrometeorological extremes are transforming hazard conditions from seasonal and localized into more frequent, widespread, and persistent environmental risks. Without timely and proactive

intervention, these hazards may escalate to a scale that threatens the ecological resilience, economic productivity, and long-term habitability of many locations within the district.

Overall analysis of hazards reveals that the central, western, and southern parts of Mokokchung are multi hazard hotspots, where high susceptibility to earthquakes, landslides, flash floods, and soil erosion overlaps. These areas therefore represent the most critical risk zones in the district, particularly for settlements located on steep slopes, along ridge lines, and major drainage corridors where exposure to multiple hazards is significantly increased. In contrast, the eastern and southeastern parts of the district generally fall within low to moderate hazard categories for most geomorphological hazards, even though localized high-risk pockets may still exist.

Addressing these challenges require a coordinated approach which may include scientific input, administrative planning, infrastructure development, and active community participation. Hazard zonation maps produced in this study can be used to guide land-use regulation and development planning. Construction in high risk zones must follow hazard-sensitive guidelines, including slope stabilization measures, effective drainage management, and environmental impact assessments. Bioengineering measures, forest protection, and vegetative restoration should be prioritized to strengthen natural resilience. Strengthening institutional mechanisms is equally important wherein, district level planning bodies need improved technical expertise, better interdepartmental coordination, and investment in monitoring systems such as rainfall gauges, slope movement sensors, and GIS based early warning systems. Local governance bodies, including village councils and community based organizations, should be integrated into hazard preparedness planning, as community participation plays a crucial role in effective response, risk reduction, and long-term resilience. Awareness, education, and training programs focusing on safe construction practices, sustainable land-use methods, and hazard preparedness must be expanded across both urban and rural areas. Schools, civil society groups, and local institutions can play a huge role in strengthening community perception of risk and encouraging preparedness behaviors. Additionally, climate adaptive agricultural practices, slope

stabilization through vegetative cover restoration, and protection of forest margins are necessary to restore natural resilience and reduce long-term exposure to hazards.

In conclusion, the hazard environment of Mokokchung district represents dynamic and evolving landscape natural geomorphic processes and human activities interact to create cumulative and interconnected risks. The findings of this study provide a strong scientific base for sustainable land-use planning and disaster risk reduction. Similar to other mountainous regions of Nagaland and Northeast India, building resilience in Mokokchung requires the integration of scientific research, effective policy support, proper infrastructure planning, and active involvement of communities. The study demonstrates that geomorphological hazards in Mokokchung have been significantly intensified by human activities which include deforestation, unplanned road construction, cutting of slopes, and rapid land-use change. The vulnerability assessment highlights that settlements, transportation networks, and livelihood systems are exposed to multi-hazard risks to a great extent. Accordingly, the hazard zonation maps produced in this study will provide a strong scientific basis for appropriate land-use planning, disaster risk reduction, and sustainable management of resources. Overall, the findings emphasize the need to integrate assessment of geomorphological hazards into development planning and policy frameworks in order to enhance resilience and promote long-term environment sustainability in Mokokchung district as well as other mountainous regions of Northeast India.

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