LANDSLIDE HAZARD ZONATION OF THINGSULTHLIAH RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM, INDIA

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

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Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Geology of Mizoram University, Aizawl

Dated: 26th May 2025

CERTIFICATE

This is to certify that the thesis entitled “Landslide hazard zonation of Thingsulthliah Rural development Block, Aizawl District, Mizoram India.” by Mr Lalchhanhima, Ph.D. Regn. No. MZU/Ph.D./1236 of 24.07.2018, for the award of Doctor of Philosophy in Geology of Mizoram University has been written under my guidance.

He has fulfilled all the requirements laid down in the Ph.D. regulations of the Mizoram University. The thesis is the result of his investigation into the subject. Neither the thesis as a whole nor any part of it was ever submitted to any other University for any research degree.

Dated: 26thMay, 2025
Place: Aizawl

(Prof. K. SRINIVASA RAO)

DECLARATION

MIZORAM UNIVERSITY

OCTOBER, 2025

I **LALCHHANHIMA**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the **Degree of Doctor of Philosophy in Geology.**

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CHAPTER – I INTRODUCTION

1. Introduction

Mizoram's topography is geologically immature. There are steep-sloped anticlinal ridges that move north-south, with synclinal troughs in between. The steep fault scarps are a result of faulting in numerous places (GSI, 2011). As a result, landslides are common throughout the entire region. The tectonically active Himalayan regions are strongly linked to landslides, which are among the most frequent natural disasters that cause damage to residential areas and the transportation system in mountainous terrain (Gurugnanam, et al., 2012). Due to population density and development in both urban and rural areas, human settlements are becoming more and more susceptible to landslides. Therefore, when landslides happen in these types of human settlements, they can turn into a catastrophe (Chandel, et al., 2011). Because of their high density and hillside positions, populations can be extremely vulnerable to natural calamities (Rawat, et al., 2010).

Over the last two-decades, there have been a multiple reports of major landslide disasters in the Aizawl district. In 1992, there was a huge landslip at the stone quarry at South Hlimen village that damaged 17 houses and killed 66 residents. Areas of the localities of Aizawl Venglai, Ramthar, and ArmedVeng were sinking in 1994, severely damaging 65 homes. About 17 homes were demolished in 1995 due to a lengthy line fracture that stretched along the Aizawl to Sairang road (National Highway 54) in the Hunthar neighbourhood. The Hunthar community, where the similar catastrophe took place in 1995, sank once more in 1999, putting the structures of around 12 houses in jeopardy. Eleven residents were evacuated from this region. Two people were killed and four others were injured when a landslip at Saikhamakawn in 2008 entirely destroyed one house. Around ten buildings were demolished and fifteen people were evacuated from Aizawl city during the 2011 monsoon season when a landslip obstructed the Lengpui Airport Road, causing chaos for passengers. A lengthy line fracture occurred in the Ramhlun Sport Complex region in 2012; around 60 households were relocated and 10 residences were demolished. 18 persons were killed in a huge landslip at a stone quarry close to Keifang locality (Saitual town) that same year. 17 people were killed in a huge landslip that occurred in the Laipuitlang neighbourhood of Aizawl city in May 2013.

Over ten people were hurt, while sixteen cars and roughly twelve houses were damaged. Numerous attempts have been made to investigate landslides in the state of Mizoram because of the numerous miniseries and issues they generate for the general populace. "A landslide is a mass movement of rock, earth, or debris down a slope," is a popular definition. (Cruden, 1991). Given the proper soil, rock, moisture, and slope conditions, they can appear on a wide variety of terrain types. A natural phenomenon of the earth’s surface geology, landslides redistribute soil and sediments. They may appear gradually or suddenly during collapses. Varnes (1978) was the first to formally propose a classification system for landslides based on material and movement types. Two words can be used to categorise and characterise a landslip: one specifies the movement, and the other characterises the substance. Rock, trash, earth, or a combination of these could be the material. Fall, tumble, slide, spread, and flow are some possible movements. Therefore, a landslip can be called a debris flow, a rock fall (where "rock" is the material type and "fall" is the movement type), etc. Although we are tempted to use the word "complex landslide," which is generally avoided, when we observe a mix of materials and motions in nature, it is advised to use a mixture of one or two of these nouns to describe a landslide. The figure 1.1 describes the shape and characteristics of a landslip. According to Varnes (1984), zoning is "Evaluating the land's homogeneous zones or domains based on the level of actual or potential danger brought on by mass movement." The "mapping of locations where landslides of a particular type and severity are equally likely to occur during a specific time frame" is known as Landslide Hazard Zonation (LHZ) (Guzzetti et al., 1999; Varnes, 1984). Maps that illustrate the spatial distribution of landslip hazard classes often depict landslip hazards as areas or zones. The basic procedures for doing this are predicting susceptible zones in space, estimating the likelihood of future landslides of a certain size, and then predicting when landslides would repeat in various susceptible zones. The primary input for risk analysis is defined as "the anticipated number of fatalities, injuries, property damage, and economic disruption resulting from a specific landslide hazard event within a designated area and timeframe," is a landslide hazard estimate (Varnes, 1984).

1.1 Factors that influence landslides

When analysing the risk of landslides, a number of elements should be taken into account (Varnes, 1984). As explained below, Soeters and Westen (1996) separated those elements into five kinds of factors.

Factors related to geomorphology include information about terrain units, geomorphologic subunits, and landslide.

1. Topography elements include concavities, slope length and direction, and data from digital terrain models.

2. Engineering geology elements include seismic acceleration, material sequences, lithology data, and geological structure.

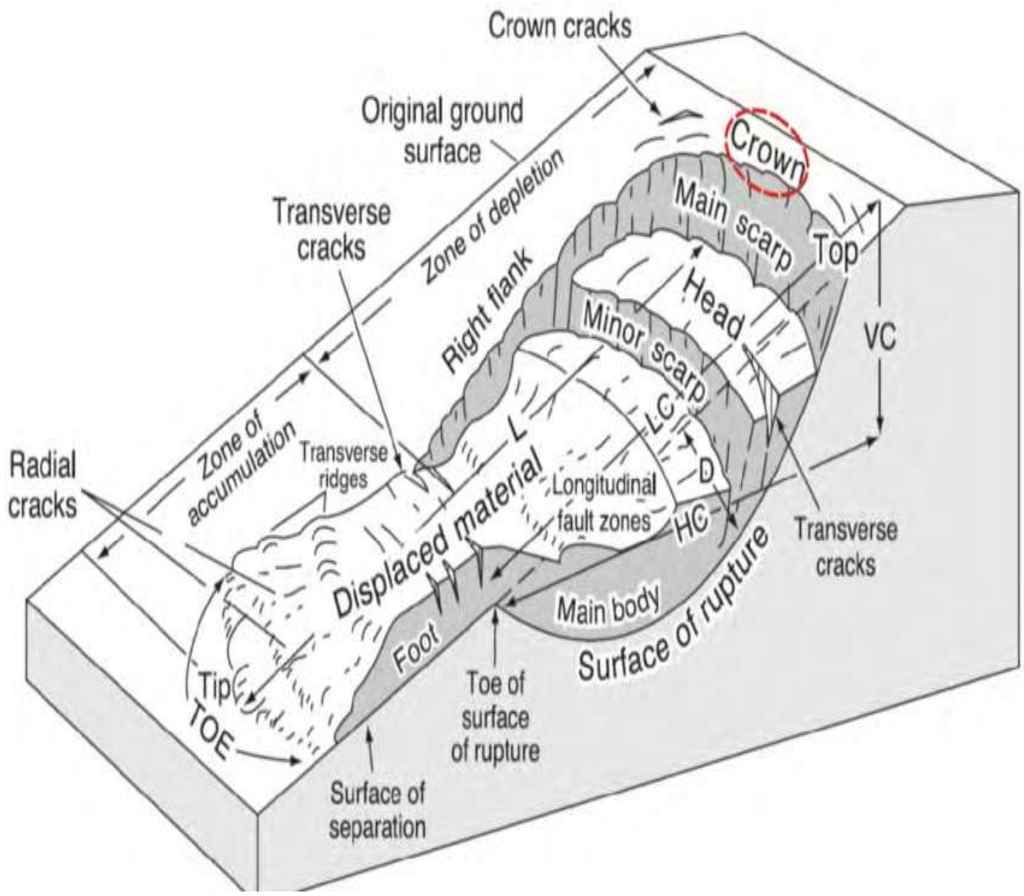

Figure 1.1. Block diagram of the idealized complex earth slide-earth flow modified from (Varnes, 1978).

3. Recent and earlier land use maps and infrastructure data are examples of land use factors.

4. Hydrological parameters include water table maps, rainfall, temperature, evaporation, drainage statistics, and catchment area.

Inclusion of all factors may be unnecessary, as it relies on the relevance to the subject area (Soeters and Westen, 1996). It facilitates the evaluation of landslip susceptibility utilising a limited number of parameters. Cruden and Varnes (1996) categorised landslide causal variables into two groups: preparation factors and triggering elements (Table 1.1). They also divided landslide causes into geological, morphological, physical, and human-induced sources, as shown in the table 1.2.

Table 1.1. The contributory factors of landslides (After Cruden and Varnes, 1996).

Geological Factors	Morphological factors
Weak materials Sensitive materials Sheared materials Jointed or fissured materials Adversely oriented mass discontinuity Aversely oriented structural discontinuity Contrast in permeability Weathered materials	Tectonic or volcanic uplift Glacial rebound Fluvial erosion of slope toe Wave erosion of slope toe Glacial erosion of slope toe Erosion of lateral margins Sub terrain erosion Deposition loading slope or its crest Vegetation loss
Physical factors	Human Induced Factors
Intense rainfall Rapid snow melt Prolonged exceptional precipitation Rapid draw down of floods and tides Earthquake Volcanic eruption Freeze and thaw weathering Shrink and swell weathering	Excavation of slope and toe Loading of slope or its crest Draw down of reservoir Deforestation Irrigation Mining Artificial Vibration Water leakage from utilities

Table 1.2. Abbreviated version of the Varne's classification of slope movements (After Varnes, 1984).

Type of the movement		Type of the materials		
		Bed rock	Engineering soil	
			Predominantly coarse	Predominantly fine
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slide	Rotational	Rock slide	Debris slide	Earth slide
	Translational			
Lateral spread		Rock spread	Debris spread	Earth spread
Flows		Rock flow (deep creep)	Debris flow (Soil creep) ↓	Earth flow
Complex	Combination of the two or more principal types of the materials movement			

1.2 General remarks

The state of Mizoram is situated between latitudes N 21°58' and N 24°35' and longitudes E 92°15' and E 93°29', in the southeast region of northwest India. The Tropic of Cancer travels through Thenzawl Town in the centre of the state. It shares an interstate boundary of 123 km with Assam, 66 km with Tripura, and 95 km with Manipur. It is bounded to the east and south by Myanmar, to the upper and lower western by Tripura state of India, and to the north-east by Bangladesh. Bangladesh (275 km) and Myanmar (475 km) are two foreign nations that share a crucial border with Mizoram. Geographically, the state is 21,087 square kilometres. The whole state is steep, with hill ranges primarily running north-south parallel to one another and grouped in an en-echelon pattern. Deep canyons and narrow valleys can be seen between the hill ranges. Approximately 900 meters above sea level is the average elevation of the hills. At present, the eleven districts that make up the state of Mizoram. In terms of administration, the state is separated into three autonomous district councils, twenty-six rural development blocks, and twenty-three subdivisions (Mizoram has a population of 10.97 lakhs, up from 8.89 lakhs in the 2001 census, according to the 2011 census. There are 1,097,206 people living in Mizoram as of the 2011 census, with 555,339 men and 541,867 women. In 2001, there were 888,573 people living there, with 459,109 men and 429,464 women. Compared to the previous decade, when it was 29.18 percent, the cumulative population growth throughout this decade was 23.48 percent.

In 2011, Mizoram accounted for 0.09 percent of India's total population. The percentage in 2001 was 0.09 percent. In Mizoram, the majority of people (87.16%) practise Christianity, making it the most common religion in the state. At 2.75 percent, Hinduism is the second most common religion in the state of Mizoram. The following religions are practiced in Mizoram state: Sikhism (0.03%), Buddhism (8.51%), Jainism (0.03%), and Islam (1.35%). A little over 0.07 percent said "Other Religion," while a little over 0.09 percent said "No Particular Religion." In Mizoram, 52.11% of the population resides in urban areas. In urban regions, there are 571,771 people, of whom 286,204 are men and the remaining 285,567 are women. Over the past decade, the urban population has grown by 52.11 percent. 998 girls for every 1000 males were the sex ratio in Mizoram's urban areas. According to the child ratio, there were 974 girls for every 1000 males in the urban area. Mizoram's urban area had an average literacy rate of 97.63 percent, with males being 97.98% literate and females being 97.02%. There were 484,841 literates in Mizoram's urban area overall.

1.3 Geomorphology

With an area of 21,081 square kilometres, Mizoram is a region that is mountainous and rocky. The Mizo Hills, also known as the Lushai Hills, are inclined to taper at both ends of their roughly north-south trend. The hills are around 900 meters high on average, and they get higher as you move east. At 2,065m above sea level, the Phawngpui on the Myanmar border is the highest mountain in the state of Mizoram. River valleys that run either north or south, forming profound ravines, divide the often-high hills. Due to recent tectonics, the state's topography exhibits significant relief because the terrain is juvenile. The topographic and structural "highs," "depressions," "flats," and "slopes" that are grouped in a linear pattern are the area's primary geomorphic features.

All topographic "depressions" are consistent with the typical major structural components, while topographic "highs" are documented in both structural "highs" and "depressions." Approximately north-south trending steep, primarily anticlinal, longitudinal hill ranges that are parallel to sub-parallel and synclinal narrow valleys are the state's physiographic manifestation. Cross-sectional faults connect the synclines and anticlines. From west to east, there is a significant variation in height between valley floors and hilltops, ranging from 200 to 600 meters (Karunakaran, 1974). There are dendritic, parallel, sub-parallel, and angular drainage patterns in the region. In addition to running parallel, lower order streams also cross topographic high and depression.

1.4 Climate

The rainfall in the state is good. The lower slopes have a humid climate during the wet season. In general, rainfall is dispersed equally. During the summer temperatures is 20° to 30°C, while winter temperatures is 11° to 21°C. Four distinct seasons can be distinguished throughout the year: spring (March–May), autumn (September–November), rainy season (June–August), and winter (December–February). Higher hills have a cool, comfortable climate throughout the rainy season, whereas the lower slopes and river gorges have a very humid climate. The recurrence of severe storms throughout the months of March through May is a fairly odd aspect of the climate in this area. Strong storms that originate in the northwest can cause significant damage to both flowering perennials and temporary homes as they rip across the entire hill range. June is when the heavy rains begin, and they last until August. The fall months of September and October are characterised by sporadic rains and temperatures that typically range from 19°C to 25°C.

Rainfall is minimal or non-existent throughout the winter months. Spring begins at the end of February and lasts until April, comes after winter. The south-west monsoon has a direct impact on Aizawl City and the neighbouring regions. The months of May through September see a lot of rain. The fall months of September and October are when the rain stops and the temperature often ranges from 19 to 25 degrees Celsius. Because of this, the region receives a sufficient quantity of rainfall each year—roughly 254 cm—which contributes to its humid tropical climate, which is marked by long summers and short winters. According to the Mizoram Pollution Control Board and Ministry of Environment and Forest (2005), the southern region of Mizoram receives 350 cm of rainfall annually, whereas the northern region receives only 208cm.

1.5 Drainage

The drainage system's ability to provide humid conditions is crucial for the development of local plants. The majority of Mizoram's vegetation is found along river channels and in nearby places, according to observations. Mizoram's physiography and geological formations essentially define its drainage pattern. The synclinal troughs that separate the parallel ranges are followed by the drainage. Across the geographical depressions and heights, the rivers, tributaries, and streamlets create an angular dendritic drainage pattern as they pass through the gorges and depressions. The streams have modest grades. The rather soft shale strata of the major rivers can occasionally be constrained. A watershed is created in the centre of the state, and the majority of the rivers flow either north or south. Because the soil is clayey, it has a low capacity to hold water. The only source of water for Mizoram's rivers, rainfall, occurs all year round with the exception of November, December, and January. But not every river is a perennial one. Mizoram is home to numerous rivers. With a length of 185.15 km, Tlawng (Dhaleshwari) is the longest river. Tiak (159.39 km), Chimtuipui or Kolodyne (130.46 km), Khawthlangtuipui or Karnaphuli (128.08 km),Tuivawl (72.45 km), Teirei (70.84 km), Tuirini (59.57 km), Serlui (56.35 km), Tuichang (120.75 km), Tuirial or Sonai (117.53 km), Tuichawng (107.87 km), Mat (90.16 km), Tuipui or Khawchhak (86.94 km), and so on are the next in The Tuirial (Sonai), the Tuivawl, and the Tlawng (Dhaleshwari) are the state's three principal rivers in the north. In western Mizoram, the Tlawng (Dhaleswari) river flows from south to north before entering the Cachar plain and joining the

Barak River. It flows magnificently in the north, starting from Zobawk hamlet (8 km. east of Lunglei town) and absorbing the tributaries, medium Lui and Bhairabi Cherra from the eastern side and Gutur (Tut) and Pakwa (Teirei) on the western flank. After roughly 60 kilometres of running parallel to the Tlawng, Tut and Teirie join it. The rivers which flow north, namely Sailut Lui, Langkaih (Longai), and Thingtlang (Singla), are also significant. In the west, Mizoram and Tripura are separated by the Longai River. In the northeastern region of Mizoram, the river Tuivawl and its tributary Tuival create a significant drainage system. These rivers serve as the boundary between Manipur and Mizoram before joining the Barak River in Tipaimukh. The Chimtuipui drainage system is significant in the southern region of Mizoram, where the Mat, Tuichang, Tyao, and Tuipui are the four tributaries of the river Chimtuipui (Kolodyne). In the southeast region of Mizoram, it serves as the border between India and Myanmar. Beginning in Myanmar's mountains, it flows first to the west, then to the south in Mizoram, before returning to Myanmar. The western drainage system is made up of the Khawtlangtuipui (Kamafuli) and its tributaries, the Tuichawng, the Phaireng, the Kun, the Deh, and the Tuiliangpni (Sazaiiiij). This river rises in Mizoram's central hills, flows west into Bangladesh at Demagiri, and then empties into the Bay of Bengal. The drainage system is parallel or rectangular in shape. Damtelui, Rangtalui, and Roi lui join from the east, while the river Tuichang and its tributaries Mat lui, Jamila lui, and Tlangpuilui join from the south-west. In a similar vein, the Tuivawl, Tuichang, and Tuilianpui run in opposing directions yet have quite long parallel paths. The Phaireng and Tuichawng join the Deh after flowing north.

1.6 Soil types

Mizoram's soil types range from sandy loam to clay; they are typically mature but leach because of the high gradient and abundant rainfall. In addition to being porous and having a low capacity to retain water, soils lack potassium, phosphorus, and nitrogen and have an acidic to neutral pH. Secondary rocks from the Barail, Surma, and Tipam series of the Miocene to Pleistocene era are the main source of Mizoram's soils. The region's terrain and climate have a major impact on soil quality. The development of the soil in the state is mostly caused by the different microclimatic conditions in the complicated physiographic structure. In contrast to the steep sides of high mountains' bare rocks, the lower slopes of hills and valleys are covered in rich, productive soils. Ridge top soils are typically shallow or have thin depths due to weathered rock underneath them. They can only support scrubs and low trees due to their inadequate moisture supply. Narrow valleys have a very small extent and are not very significant for land usage.

Flat plains have poorly drained soil. With the exception of a few flat areas, Mizoram's soils are generally well-drained and able to give a significant amount of oxygen for plant development. Most soils are capable of holding onto moisture and supplying it for the duration of a typical crop's growing season. Their limited number of mineral reserves indicates their low innate fertility. Alluvium and residual soils are the two main categories into which Mizoram's soil types fall. The foothills of the plains and valleys in the north and west are home to alluvium soils. Coarse sand predominates in these immature soils. In the majority of the state, residual soils are found on steep slopes and are further divided into lateritic brown earth and podzolic soils. The soils range in texture from clay to clayey loam to sandy loam. Although they are usually mature, the steep gradient and constant rains have caused them to leak heavily. Mizoram soils have a low capacity to retain water and are permeable. Because the rainwater carried the soils down from high elevations, they are heavier in the lowlands.

The soils have an acidic pH, yet significant leaching might occasionally get it close to neutral. The State's soils are fertile and fertilizer-responsive. Mizoram's soils are primarily composed of loose sedimentary deposits. High amounts of laterites are also present in derived soils with a red, loamy texture. Although they are low in nitrogen, humus, potassium, and phosphorus, they are high in organic carbon. However, because of the build-up of organic matter, the nitrogen concentration of eroded soil is quite high. Although the soils of Mizoram's many physiographic groups are uniform in composition, sandstones, shales, and siltstones are the primary genetic sources of the soil formation.

1.7 Flora and fauna

Wildlife and forests are among the many natural resources found in Mizoram. According to State of Environment Report of Mizoram 2016, Mizoram has 18,748 square kilometres of forest cover, or 88.93% of the state's total land area (21,087 sq km). Out of this, there are roughly 12,752 sq km of open forest (OF), 5,858 sq km of moderately dense forest (MDF), and 138 sq km of very dense forest (VDF). Furthermore, trees occupy roughly 535 square km of the area. The State's total forest and tree cover area is 19,283 square kilometres, or roughly 91.42% of the total land area. With its varied geography, high slopes divided by rivers, and a gradually sloping north and south, Mizoram has an abundance of flora and animals for the world. There are many different types of timber in the state, and bamboo is also widely distributed. The forests of Mizoram are home to a variety of mammals, including the Asiatic black bear, sun bear, tiger, clouded leopard, tiger cat, slow loris, red serow, and tiger. There are a lot of fish, amphibians, reptiles, and invertebrates in Mizoram. In addition to a wide variety of invertebrate fauna, the state is home to eight different species of monkeys.

1.8 Rainfall

Due to the Bay of Bengal's close proximity to the ocean, any cyclonic development there has a significant impact on the state's weather. In addition to the monsoon season, the state also receives a significant amount of rainfall whenever a cyclonic storm passes through. Mizoram has a year-round temperate climate that is neither extremely hot nor chilly. The south-west monsoon has a direct impact on the entire state, which receives enough rainfall. The state has a humid-tropical climate, with long summers and significant rainfall and brief winters. The temperature varies very little, peaking between May and July before beginning to drop as the monsoon season approaches. According to the State Metrological Centre (2016), rainfall in the study region peaked in 2006 (3375.4 mm) and decreased in 2010 (2047.4 mm) between 1986 and 2015. In Mizoram, landslides brought on by monsoon rainfall are a frequent hazard that results in fatalities as well as significant property and infrastructure damage. The annual rainfall data from 1986 to 2015 is displayed in table 1.3 and figure 1.2.

Table 1.3. The average monthly rainfall distribution of Aizawl district during 1986-2015.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1986	5.7	21.3	58.3	360.3	247.3	343.3	490.7	399.7	320	204.3	188.7	62.7	2702.3
1987	15	40.7	64.3	148.3	162.3	480.3	438.7	481.7	477	134	134	102.7	2679
1948	0.0	53.7	80.7	185	488	380.3	439.3	429.7	320	279.7	58.7	4.3	2719.3
1989	0.0	32.2	34.3	148.3	138.3	498.3	499.3	479.3	459.7	396.7	3.3	5.7	2695.6
1990	1.3	55.3	290.7	339.3	297	393	353.3	456	338.3	193	138.3	79.7	2935.3
1991	26.7	55.0	46.0	375	523.7	441	292.7	368.3	279	337.7	36.7	25	2802.6
1992	2.0	49.7	40.0	124	253.7	375.7	393.3	456	479.3	363.3	36.7	25	2802.6
1993	10.7	98.7	90.0	135.3	427.3	534.7	502.3	419.7	315.7	192.7	12.7	0.0	2739.6
1994	14.3	14.0	191	220	140.7	371	434.3	482	248.7	137.7	24.7	0.0	2278.3
1995	0.0	42.0	131.3	88.3	427	597.7	399	654	319.3	230	297.3	0.0	3186
1996	10.7	26.0	367.7	131.7	291	377.7	475	426.7	569	155.7	37.3	0.0	2868.3
1997	8.7	24.7	226.3	117.3	320	334.3	797.3	362	555.3	69.7	45.3	82.7	2943.6
1998	63.0	33.3	147	169	456	306.3	575.3	496.7	303.3	125.7	55	0.0	2730.6
1999	0.0.	0.0	33.5	30.5	578.3	488.2	532	493.8	540.8	259.8	23.7	14.3	2995
2000	22.2	28.5	152.7	303.2	517.2	336.3	258.7	657.7	330.7	268.3	28.3	0.0	2903.6
2001	0.0	57.3	67.7	103.7	398.7	525.7	390.7	410.7	407.7	328	120	0.0	2810
2002	24.7	0.5	68	179.8	587	363	505.7	519	273.2	188.8	78.3	0.5	2788.5
2003	2.8	15	130.6	166.2	333.2	833.6	374.6	469.2	399	186.6	0.0	59.8	2970.6
2004	0.0	0.0	18	379.3	262	535.8	865.5	450	395.3	195.8	6.5	0.0	3108.3
2005	9.8	11.3	179.1	86.6	405.5	178.7	545.4	337.4	386.9	241.8	43	10.9	2436.4
2006	0.0	2.2	2.7	67.4	578.8	685.5	491.3	346.9	393.7	144.4	4.4	0.0	2717.3
2007	0.0	70.7	28	343.9	411.9	548.2	452	562.5	686.5	147.2	124.5	0.0	3375.4
2008	49.3	10.6	40.5	50.8	260.8	416.6	433.5	497.2	354.8	195.7	20.3	0.0	2330.1
2009	0.0	0.5	36.5	153	203.4	331.9	339.4	478.8	278.1	196.5	29.3	0.0	2047.4
2010	0.0	10.9	131.2	298	407.4	496.7	387.4	466.7	462.9	276.3	15.4	59.6	3012.5
2011	19.3	0.5	99.6	125.6	453.5	477.8	349.6	534	399	118.6	0.0	0.0	2577.5

2012	22	15.2	27.1	438	258	536	391	496.2	465	186	104	0.0	2938.6
2013	0.0	4.1	4.5	91.1	634.2	399.6	445.4	586.6	383.4	159.3	0.0.	0.0.	2708.2
2014	0.0	21.8	37.3	86.4	466.4	320.7	447.3	313.3	481.6	106	2.8	0.0	2283.6
2015	27.9	15.6	35.7	374.8	245.1	412	504.3	589.1	303.1	219.6	4.2	0.8	2732.1
Average	12.0	27	95.3	194	372.5	444	460.1	470.7	474.7	253.9	60.2	28.3	2756.5

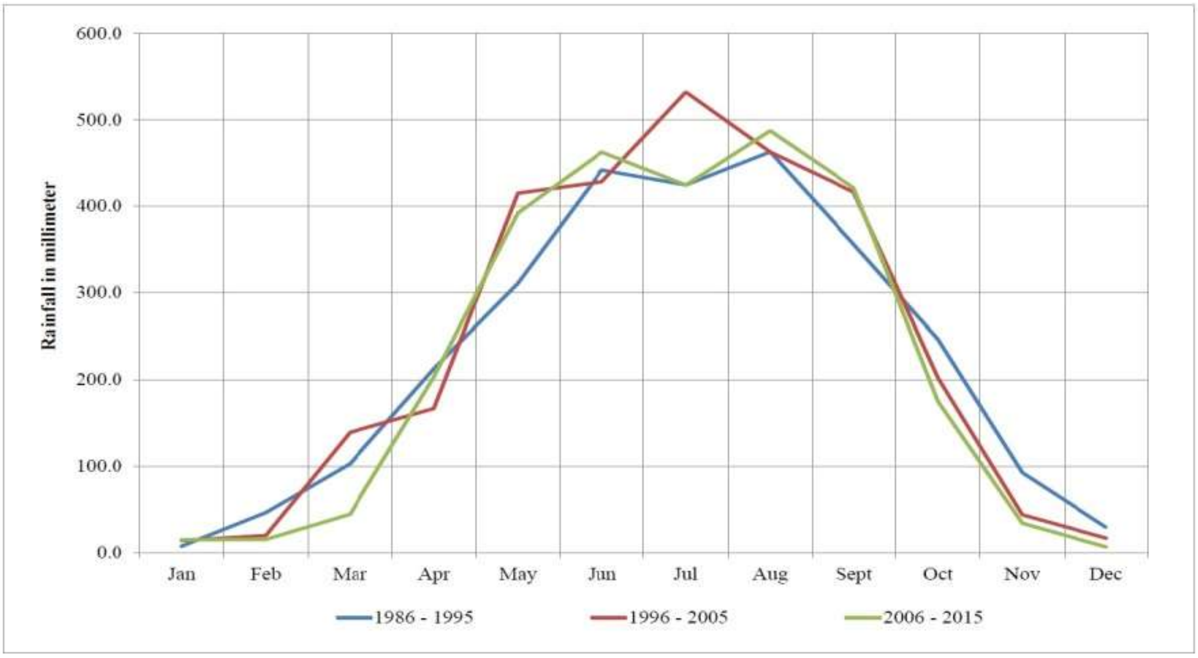

Figure 1.2. The decal changes of rainfall (mm) distribution in Aizawl district (1986- 2015).

1.9 General Geology

Mizoram is a part of the Cenozoic-aged Tripura-Mizoram sedimentary basin (Evans, 1964). Here, the succession alternates between arenaceous and argillaceous. In terms of structure, the state has longitudinally plunging anticlines and synclines as well as N-S trending lines (Ganju, 1975, Nandy, 1982, and Ganguly, 1983). There are a few pockets of shell limestone, calcareous sandstone, and intra-formational conglomerates, but the main rock types exposed in the area are sandstone, siltstone, shale, mudstone, and their admixture in various proportions. The rock formations generally trend N-S with dips ranging from 20º to 50º either east or west (Karunakaran, 1974). These are arranged in ascending order according to the Barail, Surma, and Tipam Groups. As determined by Karunakaran (1974) and Ganju (1975), the state's geologic sequence is listed in Table 2.1.It is debatable that the Barail succession exists in Mizoram. Barail succession has been demonstrated to exist in the eastern region ofthe State, near Champhai, by geologists from the Geological Survey of India, including Munshi (1964), Nandy (1972, 1982), and Nandy et al. (1983). However, geologists associated with the Oil and Natural Gas Corporation of India, including Ganju (1975), Ganguly (1975), Shrivastava et al. (1979), and Jokhan Ram and Venkataraman (1984), believe that the Barails are not found in Mizoram and that the rocks surrounding Champhai belong only to the Surma Group. DifferentLith units' spatial distributions show that the anticlinal cores of high amplitude folds are the only places where the Lower Bhuban succession is found. Usually found on fold limbs, the Middle Bhuban succession also occupies the centres of low amplitude anticlines.

While they are restricted to the synclinal cores in central and eastern Mizoram, the Upper Bhuban rocks form anticlines in western Mizoram. In the western and northwest regions of the State, Bokabil rocks are restricted to the cores of synclines in relation to Tipams (Ram and Venkataraman,1984).

It is believed that the Mizo Hills are a structural component of the mobile belt, which is made up of elongated, double plunge folds that are extremely tight and sub-parallel. With large saucer-shaped synclines, the folds are en-echelon or alternating anticlines that trend sub-meridionally. Westward convexity and a somewhat arcuate shape characterise the fold belt (Srivastava, et al., 1979). The succession likewise gets younger in the same direction as the deformation intensity gradually decreases as one moves over the fold belt from east to west. Therefore, younger rock formations folded into narrow, box-like anticlines alternate with wide and flat synclines along the western flanks of the state and the surrounding regions, such as Tripura and the Cachar district of Assam. In contrast, the eastern part of the state is characterised by relatively older rock formations folded into tight, linear anticlines and synclines (Ganguly, 1983).

1.10 Objectives

The main objective of the study is to prepared Landslide Hazard Zonation map demarcating different hazard zone ranging from high to low zone in Thingsulthliah RD block area. Land slide hazard zonation mapping plays a vital role in road construction and planning of town, city and rural areas. The present study will provide landslide hazard area and which may act a tool for mitigating landslide in the study areas. The objectives of the study are as follow:

1. Thematic layers of lithological, structural, slope, slope aspect, Land use and land cover, relative relief, geomorphology will be prepared in GIS environment with a scale of 1:25000.

2. Preparation of Landslide Hazard Zonation map.

3. To suggest remedial measures to mitigate landslide in the study area.

Table 1.4. The Stratigraphic Succession of Mizoram (Modified after Karunakaran, 1974 and Ganju, 1975).

<table>
<tr><th>Age</th><th>Group</th><th>Formation</th><th>Unit</th><th>Generalized lithology</th></tr>
<tr><td>Recent</td><td>Alluvium</td><td>-</td><td>-</td><td>Silt,clay and gravel</td></tr>
<tr><td colspan="5">Unconformity</td></tr>
<tr><td>Early Pliocene to Late Miocene</td><td colspan="2">TIPAM (+900m)</td><td>-</td><td>Friable sandstone with occasional clay bands</td></tr>
<tr><td colspan="5">——————Conformable and transitional contact——————</td></tr>
<tr><td rowspan="7">Miocene to Upper Oligocene</td><td rowspan="7">S
U
R
M
A
(+5950m)</td><td>BOKABIL (+950m)</td><td>-</td><td>Shale, siltstone and sandstone</td></tr>
<tr><td colspan="3">———Conformable and transitional contact———</td></tr>
<tr><td rowspan="5">B
H
U
B
A</td><td>Upper Bhuban (+1100m)</td><td>Arenaceous predominating with sandstone, shale and siltstone</td></tr>
<tr><td colspan="2">–Conformable and transitional contact–</td></tr>
<tr><td>Middle Bhuban (+3000m)</td><td>Argillaceous and predominating with shale, siltstone shale alternations and sandstone.</td></tr>
<tr><td colspan="2">–Conformable and transitional contact–</td></tr>
<tr><td>Lower Bhuban (+900m)</td><td>Arenaceous predominating with sandstone and silty shale</td></tr>
</table>

		N		
———————————Unconformity obliterated by faults———————————				
Oligocene	BARAIL (+3000m)	-	-	Shale, siltstone and sandstone
———————————Lower contact not see———————————				

1.11 Location of study area

The study area is located in the central region of the state, between 92° 47.090'E and 93° 02.55''E and 23° 30.40'N and 23° 50.75'N in the Aizawl district (Figure 1.3). It is included in Survey of India topographical maps No. 84A/13, 84A/14, 84E/1, and 84E/2. The Tlangnuam and Aibawk RD blocks border the region on the west, Darlawn borders it on the north, Champhai district borders it on the east, and Serchhip district borders it on the south. The settlements and the road network distribution in the study area is shown in the figure 1.4.

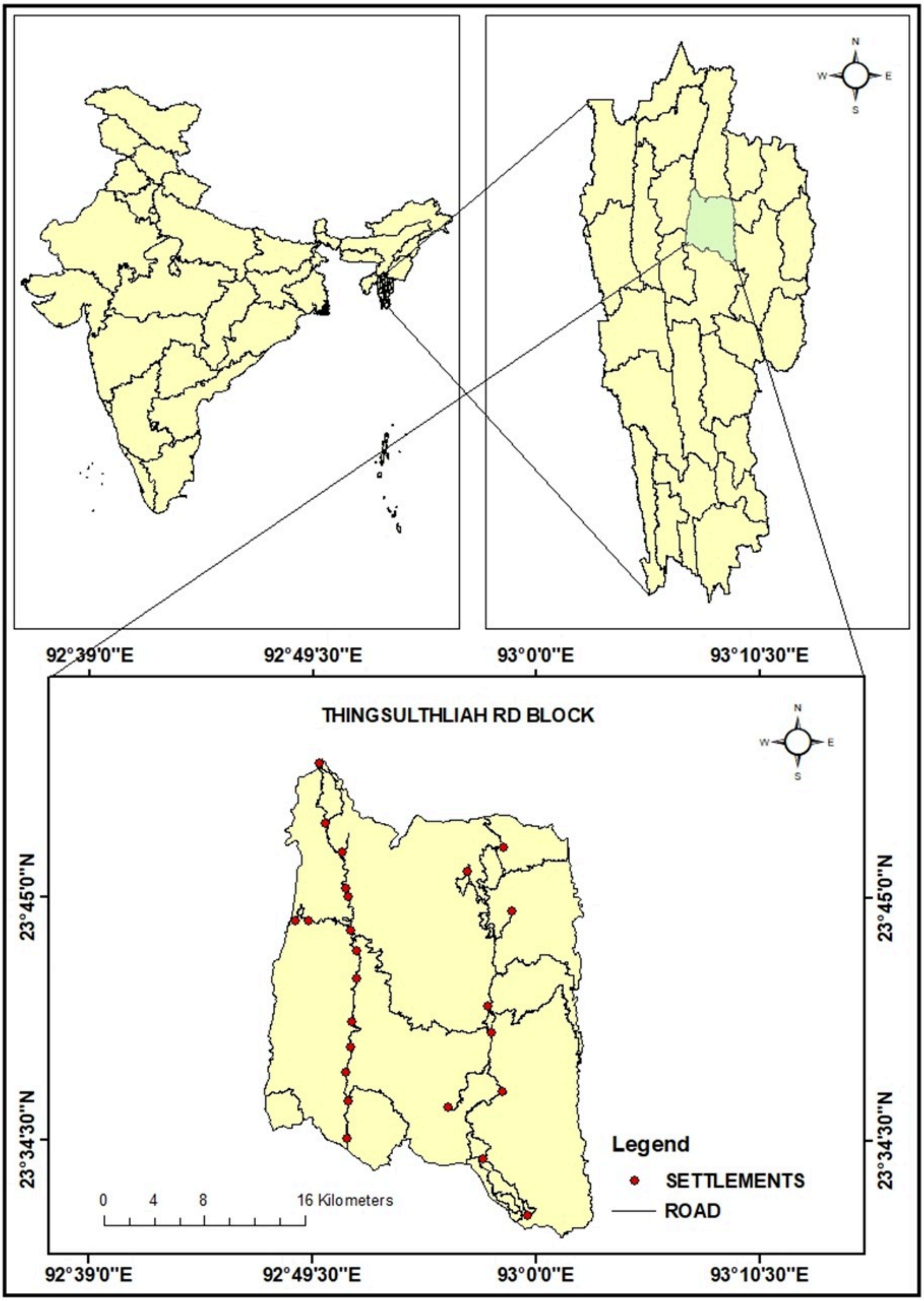

Figure1.3. Location map of the study area.

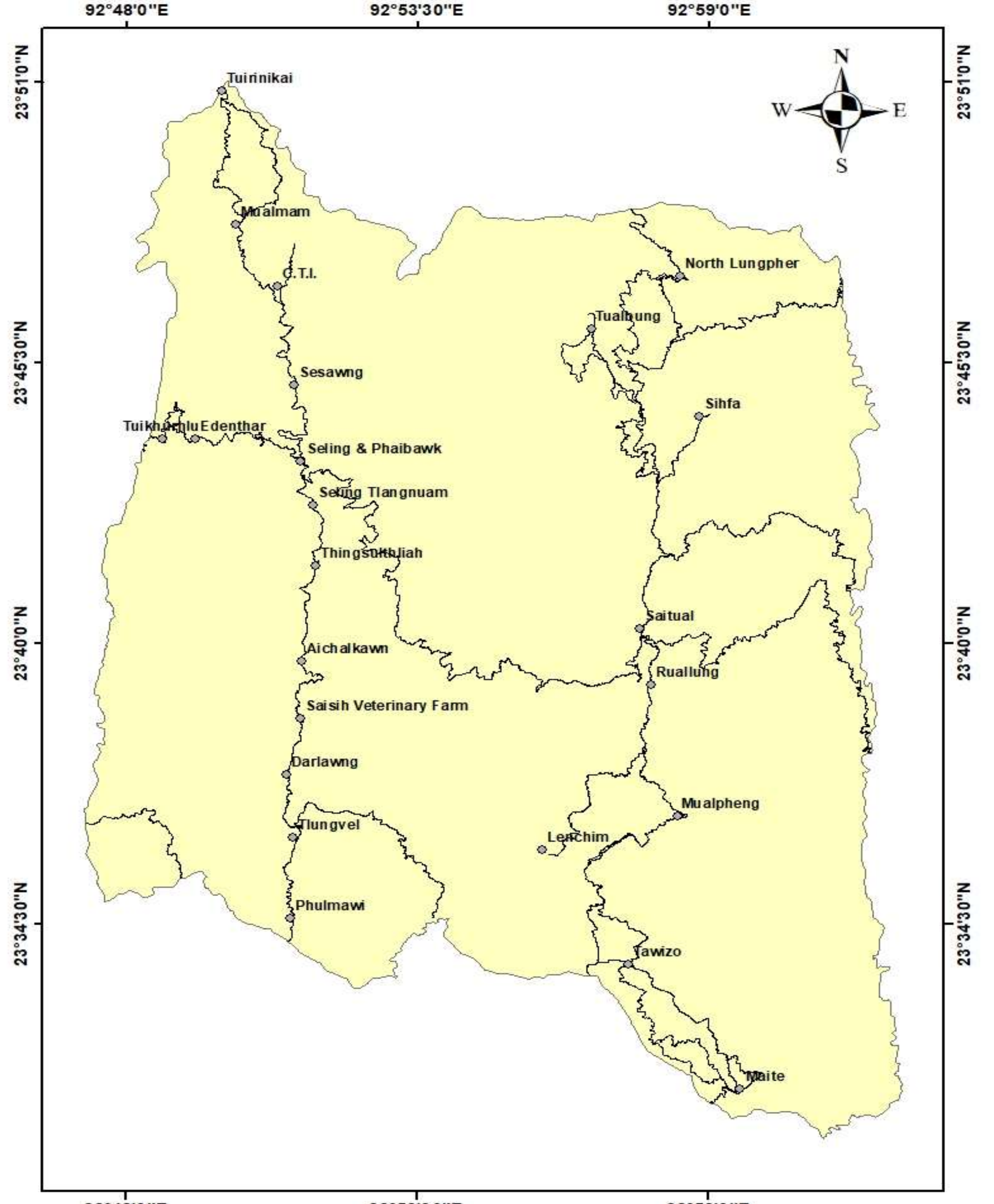

Figure 1.4.The settlements distribution and the roads network in the study area.

The major administrtive divisions in the state of Mizoram as per the census 2011 is divided in to eightdivisions (Fig. 1.5). The settlements in the study area is 30 as per the census 2011 and distrubution of the population in the Thingsulthliah RD block shown in Table 1.5.

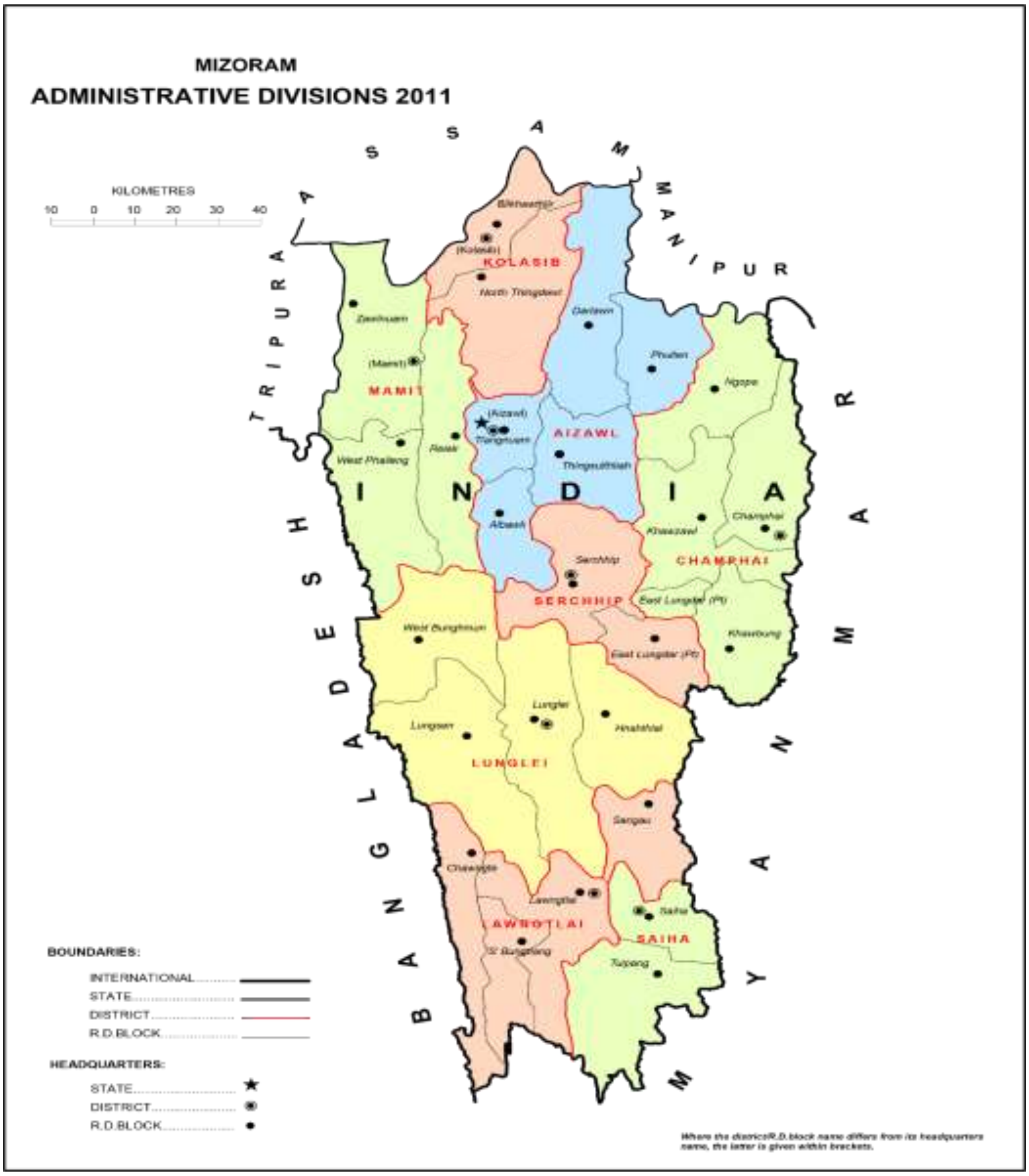

Figure 1.5.The Administrative divisional blocks in the state of Mizoram.

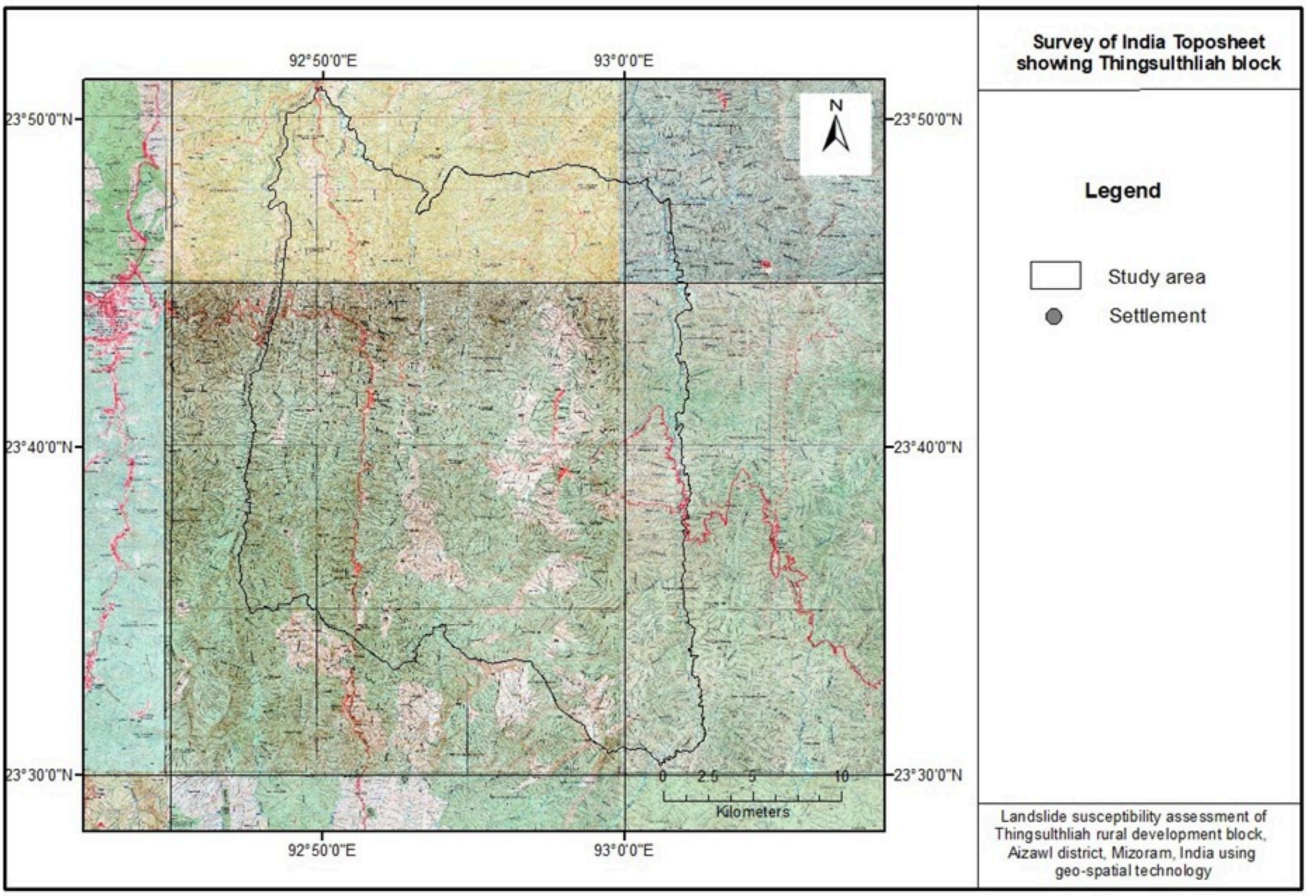

Figure 1.6. The toposheet of the Thingsulthliah RD Block

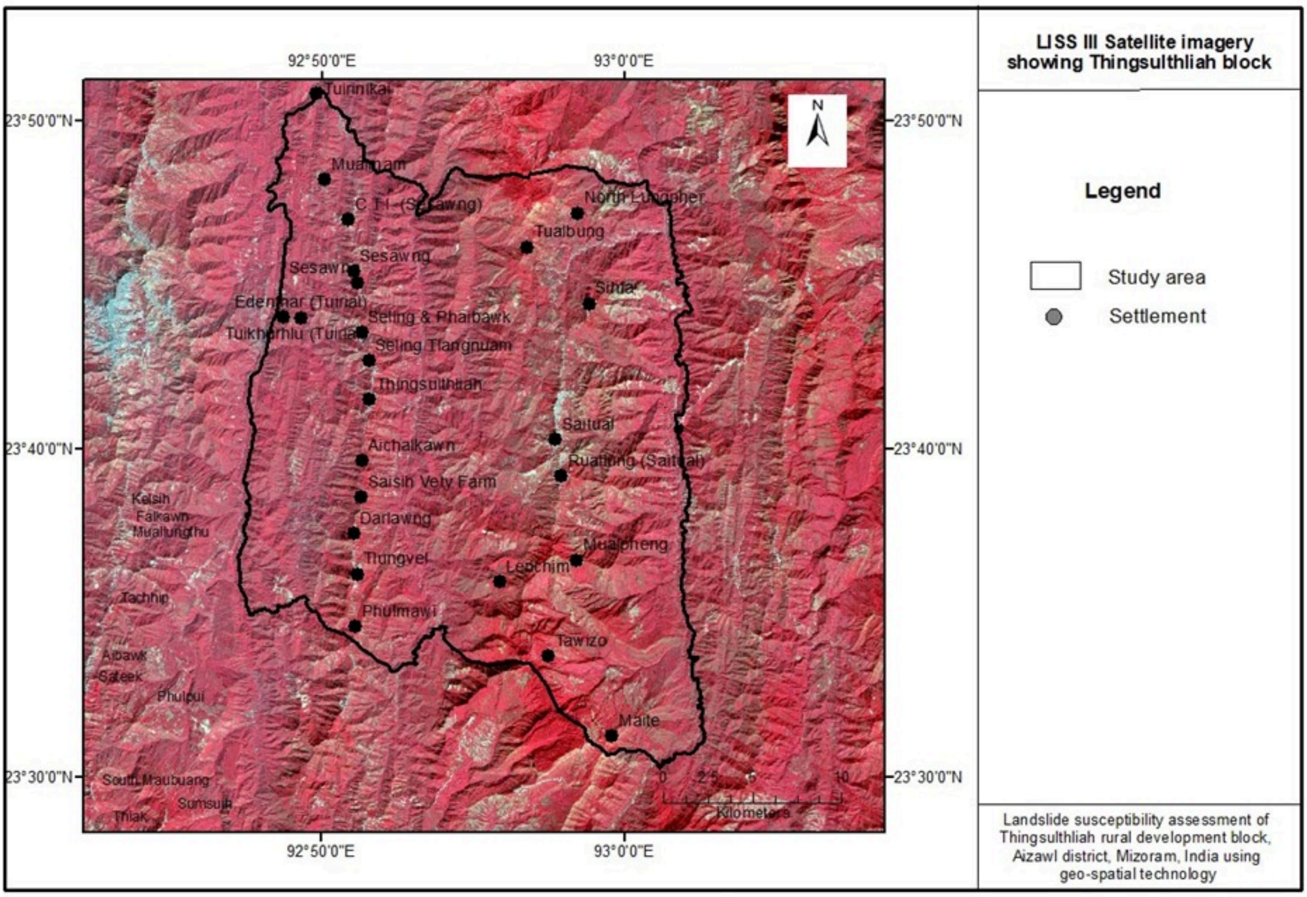

Figure 1.7. The LISS III imagery of the Thingsulthliah RD Block

Table 1.5. The statistical details of the Thingsulthliah RD Block (Census 2011).

Sl. No.	Name of the village	No of households	Population as per the 2011 census		
			Male	Female	Total
1	Saitual (Town)	2,457	5,727	5,892	11,619
2	Aichalkawn	23	48	47	95
3	Baktawn	551	1586	1634	3220
4	Buhban	118	310	293	603
5	Buhkangkawn	40	75	76	151
6	C.T.I.Sesawng	102	241	243	484
7	Chanin	33	77	70	147
8	Darlawng	160	117	108	653
9	Dilkhan	48	579	548	225
10	Edenthar	7	12	13	25
11	Hmawngkawn	34	89	81	170
12	Hualtu	186	512	448	960
13	Khumtung	236	582	568	1150
14	Lenchim	76	178	160	338

15	Maite	180	496	498	994
16	Mualmam	42	91	82	173
17	Mualpheng	157	366	368	734
18	N. Lungpher	170	437	420	857
19	Phaibawk	16	37	32	69
20	Phulmawi	66	146	131	277
21	SaisihVety	7	17	16	33
22	Seling	468	2889	1138	1151
23	Seswng	562	1371	1351	2722
24	Sihfa	209	482	476	958
25	Tawizo	103	419	236	183
26	ThingsulTlangnuam	305	1587	920	667
27	Thingsulthliah	724	1663	1739	3402
28	Tlungvel	559	2529	1238	1291
29	Tualbung	171	824	418	406
30	Tuikhurhlu	45	96	94	190

CHAPTER - II LITERATURE REVIEW

Literature Review

A comprehensive review of various journals at the international, national, and state levels reveals that different researchers have employed diverse methods and techniques to generate landslide hazard zonation (LHZ) maps. The approaches and methodologies vary significantly across studies, indicating that there is no standardized method for creating such maps. Instead, the choice of method depends on the researcher's objectives and selected approach. Below is a summary of significant LHZ-related studies carried out by various authors:

Castellanos Abella and Van Westen (2008) developed a landslide vulnerability assessment model using a multi-criteria analysis approach. They applied a subjective methodology by assigning hazard values to each pixel in a map indicating areas prone to landslides, based on the conditions under which slope failures occur.

Choubey and Lallenmawia (1987) conducted a study on landslides in specific areas of Aizawl city. Their research highlighted that tectonic activity, geological structures, and variations in geological settings played key roles in triggering landslides in these locations.

Choubey (1992) studied landslides in the Vaivakawn area using geotechnical laboratory techniques to simulate sliding movements and proposed corrective measures for the affected areas.

Gupta and Joshi (1990) utilized GIS-based techniques to create a zonation map for landslide hazards for the Ramganga catchment in the Himalayas. They identified seismic activity and rainfall as significant contributing factors, along with land use, tectonic features, and local geomorphological characteristics like sharp river bends and undercut stream areas.

Gupta et al. (1993) prepared an LHZ map of the Upper Satluj Valley in Kinnaur District, Himachal Pradesh. Their findings showed that 13% of the total area fell within anextremely high-risk hazard zone, 10% in a high-risk zone, 34% in a moderate risk zone, another 34% in a low-risk zone, and 9% in a very low risk zone.

Guzzetti et al. (1999) discussed the flexibility of the heuristic methodology, a non-direct mapping technique that involves identifying numerous controlling factors that potentially contribute to landslides and analyzing these factors in relation to slope instability.

Lalbiakmawia and Lallianthanga (2014) prepared a landslide susceptibility zonation map for Kolasib District in Mizoram at a 1:50,000 scale, categorizing the hazard zones into moderate, low, very low, high, and very high-risk areas.

Laldinpuia et al. (2011) investigated the RamhlunVengthar landslide in Aizawl using geotechnical methods. Their study found that steep slopes, poor drainage, high rainfall, and toe erosion contributed to landslides, reducing shear strength and causing significant damage to houses.

Laldinpuia et al. (2013) examined a catastrophic rockslide in the Laipuitlang area of Aizawl that resulted in 17 fatalities and damage to several houses. They attributed the landslide to a combination of porous rock layers, steep slopes, heavy rainfall, road cutting along the dip direction, and the overburden of concrete structures.

Lallianthanga et al. (2013) employed the weightage scheme from the National Remote Sensing Agency (NRSA, 2001) combined with the strength assessment method used by Joyce and Evans (1976) to map landslide hazards in Mamit Town, Mizoram. They also provided suggestions for remedial measures.

Lalbiakmawia and Laltlankima (2016) prepared an LHZ map along the Aizawl city–Lengpui Airport road, categorizing the area into six hazard zones and offering recommendations for mitigation.

Lallianthanga and Laltanpuia (2013) used high-resolution satellite imagery and GIS to conduct a landslide study in Lunglei Town. They applied the heuristic method, assigning ranks and weights based on expert knowledge, and classified the hazard zones into five categories ranging from low to very high risk.

Lalrokima et al. (2016) carried out LHZ mapping in Saiha District, Mizoram using remote sensing and GIS. They integrated geological and environmental data and assigned weightages to various parameters, concluding that 9.89% of the area is very high hazard zone, 24.35% is high hazard zone, moderate hazard zones cover 42.72%, low hazard zones cover 19.96%, and very low hazard zones occupy 2.22%.

Lalramdina (2019) observed that anthropogenic activities, combined with aspects of nature such as slope, lithology, geological structure, rainfall, and infrastructure development (e.g., buildings and road cutting), significantly contributed to landslides in Serchhip Township.

Laltlankima et al. (2020) conducted an LHZ study along a national highway in Aibawk Block, categorizing the area into five hazard zones. They assigned different ranks and weightages to thematic layers.

Lawmkima et al. (2011) studied landslides in Sairang near Aizawl using geotechnical analysis. Their findings indicated that the occurrence of shears b and clay beds with enlargement and contraction attributes to slope instability.

Kumar et al. (1996) investigated the unstable issues at the South Hlimen Quarry site in Mizoram. It attributed the quarry's instability to large block sizes, smooth joint surfaces, and heavy rainfall, which weakened the cohesion of the rock joints.

Mazumdar (1980) created the first LHZ map of Northeast India at a 1:100,000 scale. He categorized the region into six hazard zones based on geology, geomorphology, and hydrology. According to his study, Mizoram falls in a moderate to moderately high-risk zone.

Micro-level LHZ plotting of Aizawl City using satellite data and GIS technologies at a 1:30,000 scale conducted by MIRSAC (2008)

MIRSAC (2011) utilized the satellite data from the CartoSat V stereo pairs and QuickBird (0.6 m resolution), along with the Survey of India topographic maps, to perform micro-level LHZ plotting of the Aizawl City and other town areas. They divided the areas into five hazard zones ranging from very low to very high risk.

Kartic Kumar et al. (2013) prepared a landslide vulnerability map for the Kothagiri Region in the Western Ghats, Tamil Nadu, using rating values. The map was divided into four vulnerability classes range from low to very high risk. Their analysis showed that slope, drainage density, geological features, and land cover significantly contributed to landslide susceptibility.

Naithani (2007) conducted macro-level LHZ mapping using univariate statistical analysis in the Garhwal Himalaya. He found that geological structures and lithology were responsible for over 72% of landslides in the region.

Moirangcha et al. (2014) assessed landslide and seismic hazards in Aizawl by integrating geological, geotechnical, and geophysical data into a GIS platform. Using a 1:25,000 scale, they found that 5% of the area fell into a high hazard zone, 41.3% into a moderate hazard zone, and 53.7% into a low hazard zone. A separate seismic hazard map revealed that a very high hazard zone is 13% of the area, a high hazard zone is 39.1%, a moderate hazard zone is 42.3%, and a low hazard zone is 5.6%.

Raju et al. (1998) created a preliminary LHZ map for southern Mizoram, covering an area of 6,700 sq. km. They found that 10% of the area was in the high hazard zone, 60% in the medium hazard zone, and 30% in the low hazard zone.

Tiwari and Kumar (1997) examined the 1992 South Hlimen landslide, which claimed over 100 lives. They attributed the landslide to the blocky nature of sandstone and uncontrolled slope cutting through blasting.

Tiwari et al. (1998) conducted LHZ mapping along the Hnahthial-Hrangchalkawn road section in Lunglei District, Mizoram. 104.32 sq. km of hillside slopes was mapped and classified the area into low, medium, and high hazard zones.

CHAPTER - III METHODOLOGY

3.1 INTRODUCTION

The methodology for landslide hazard zonation aims to map hilly terrains with respect to instability, providing guidance for future development planning. The hazard map categorizes the area into five degrees of instability, useful for terrain evaluation (Sarkar, Kanugo, and Mehrotra, 1995). This research focuses on generating a landslide hazard zonation map using a heuristic approach within a Geomorphic Information System (GIS) environment. Recent advancements, such as integrating satellite imagery and digital elevation models, have enhanced the identification of landslide occurrences (Barlow et al., 2006).

For studying landslides in hilly terrains like Mizoram, remote sensing and GIS methods are more reliable than direct mapping. GIS offers several advantages, including heuristic approaches, statistical analysis, physically-based modelling, probabilistic methods, and database processing. These tools have been widely implemented by researchers to analyse the relationship between slope failure and causal factors, aiding in the creation of landslide hazard zonation maps (Zhau et al., 2002).

Key concepts related to landslide hazards, as defined by Varnes (1984), include:

- **Landslide Susceptibility**: The possibility of a landslide occurs in a certain area due to local topography. Susceptibility does not take the likelihood of triggering events into account.
- **Landslide Hazard**: The possibility of a destructive landslides to occur in a region, determined by spatial scale and temporal probabilities.

Landslide susceptibility assessment provides essential insights into identifying areas at risk of landslides. Susceptibility maps and inventories are critical tools for managing landslide-prone regions across the country (Spiker and Gori, 2000). The primary objective of a landslide susceptibility map is to highlight zones that probably influenced by landslides in the imminent due to nature or anthropogenic activities. The effectiveness of these maps, they must achieve sufficient accuracy to support local mitigation strategies.

This study employs standard satellite imagery interpretation procedures and GIS techniques to generate thematic information, which is subsequently transformed into various map formats. The methodology follows a systematic method designed to evaluate landslide

Susceptibility in the study area by integration of remote sensing data, limited fieldwork and GIS techniques. The steps involved in the process are outlined in a flowchart, as depicted in Figure 3.1.

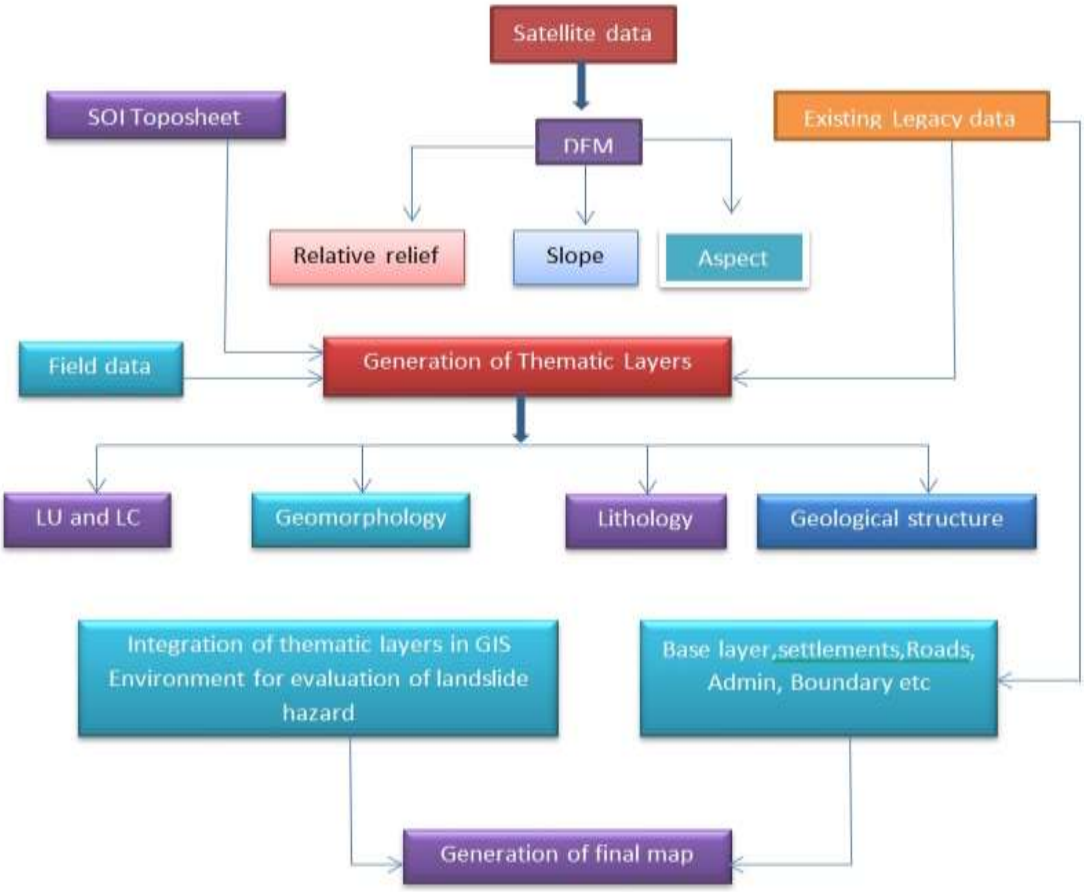

Figure 3.1. The flow chart showing the methodology for the landslide hazard assessment.

The methodology is divided into two primary components. The first involves the preparation of individual thematic maps, including lithology, geomorphology, geological structures, and base map details. These are created through the visual interpretation of satellite data and Survey of India topographic maps, supplemented by limited fieldwork and existing data.

The second component involves the creation of a landslide hazard map by integrating thematic data. The methodology follows the approach established in the Landslide Hazard Zonation Project conducted by the National Remote Sensing Agency in 2001.

On-screen Data Interpretation: Satellite data, top sheets, and geo-referenced GSI maps in digital formats are displayed on a computer screen for analysis. The generation of thematic information, including geomorphological, lithological, structural, and hydrological details, along with base map features, is accomplished through on-screen visual interpretation techniques. The interpreted data are then cross-verified and refined using ground truth information gathered during limited fieldwork.

The output from this process is generated in vector format, comprising point, line, and polygon features, which facilitate advanced GIS analyses.

The landslide susceptibility assessment provides vital insights into the potential risks of landslides. Landslide inventories and susceptibility maps are particularly significant for regions prone to landslides across the country (Spiker and Gori, 2000). Landslide susceptibility map is used to identify zones that may be affected by probable landslides due to natural or anthropogenic activities. These maps must be sufficiently accurate to support local mitigation efforts effectively.

Thematic mapping:

All the data related to factors influencing landslide occurrence are organized into thematic layers. Ground conditions are systematically analyzed, with all relevant elements carefully considered for mapping. Omitting even a single element can result in inaccurate conclusions.

i) Base Map Layer: This layer includes four categories of information:

a) Administrative boundaries

b) Settlement distribution

c) Road networks

d) Drainage distribution

Administrative units are represented as polygon shapefiles, settlements as point shapefiles, and road networks, drainage systems, and railway lines as separately linear shapefiles.

Landslide susceptibility mapping methods are broadly classified in three categories: qualitative, semi-quantitative, and quantitative (Lee and Jones, 2004). The qualitative approach is topic-focused and effective for large areas, while the quantitative approach is object-focused and identifies relationships between environmental variables and past landslides. Researchers have developed several methods based on these techniques, such as the heuristic approach (Ruff and Czurda, 2007), the statistical approach (Carara et al., 1991), the deterministic approach (Soeters and Westen, 1996), and the probabilistic approach (Guzzeti et al., 2005).

ii) Geomorphology Layer

All landforms or geomorphic units within the study area are mapped as polygon features and labeled with their respective geomorphic names. During the delineation of these units, toposheets were used to understand relief variations and other topographic characteristics. A geomorphological map, showing various landforms, is prepared by referencing the lithological map, allowing each rock type to be classified into corresponding geomorphic units or landforms.

iii) Lithology Layer

All rock formations present in the study area are mapped as a layer of polygon features and annotated with their respective litho-stratigraphic names, such as sandstone or shale. Using this "prior knowledge," satellite imagery is analyzed to match distinct image characteristics with specific rock types. When contrasting rock types are present, boundaries appear clearly on satellite imagery due to variations in tones or landforms. In cases where boundaries are less distinct, additional evidence is used to define the separations between rock types.

iv) Structural Layer

Geological structures in the area, such as faults, fractures, or lineaments that serve as weak or vulnerable zones, are mapped as line features.

The methodology involves identifying landslide hazard classes by considering factors that influence hazards. This process includes the creation of individual thematic maps—such as geomorphology, lithology, structural, and base maps—using visual interpretation and extraction from satellite data in conjunction with pre-existing information.

3.2 Heuristic approach

The heuristic approach relies on the expertise of geomorphologists to assess landslide hazards. The key input of landslide hazard zonation is the landslide inventory map, followed by environmental factors, with experts assigning weighting values based on their judgment. This approach incorporates hierarchical levels and employs various methods for determining weighting factors. The hierarchical heuristic model is often integrated into a Decision Support System (DSS) to facilitate spatial decision-making (Castellanos and Van Westen, 2003).

The method may generally be separated into two types of analysis: qualitative map combination and direct mapping analysis.

In direct mapping analysis, geomorphologists assess susceptibility directly in the field, relying on their individual experience. In qualitative map combination, experts assign weighting values to different parameter classes based on their knowledge.

A significant challenge of the heuristic approach lies in determining precise weighting values, as the method is inherently subjective and depends heavily on expert judgment.

3.3 Statistical approach

The statistical method to landslide susceptibility assessment aims to enhance objectivity in hazard evaluation (Van Westen, 1993). This method is particularly effective when past landslide events are critical for predicting future occurrences. The cornerstone of this approach is the landslide inventory map, which provides data on past events. By statistically analyzing the combinations of causal factors, this approach generates quantitative estimations of landslide probabilities for areas currently unaffected by landslides but sharing similar conditions (Soeters and Van Westen, 1996).

The statistical method can be categorized into two types of analyses:

- **Bivariate Statistical Analysis**: Examines the relationship between each causal factor and the landslide occurrences independently.
- **Multivariate Statistical Analysis**: Considers multiple causal factors simultaneously to analyze their combined effect on landslide susceptibility.

. 3.4 Physically-based modeling approach

Assessment of landslide hazard with the stability of slope model involves calculating safety factors to provide a quantitative stability index. Unlike other methods, this approach quantifies stability by evaluating safety factors. However, it has notable limitations. The complex calculation of safety factors, the need for extensive datasets, and the challenge of measuring the spatial distribution of parameters are significant obstacles (Van Westen, 1993). Experts have pointed out the additional drawbacks. Van Westen (1993) noted that due to insufficient input data—such as groundwater levels, soil profiles, and geotechnical characteristics—the method is only practical at small to medium scales. The safety factor values are not absolute; instead, they reflect varying conditions of slip surfaces and groundwater depth. According to Soeters and Van Westen (1996), this approach is suitable when the geomorphological and geology in the study area are relatively homogeneous, and the existing landslide types are simple.

This method utilizes the interpretation of field observations, remote sensing data, discussions with local people and past analyses of landslides within the study area (Soeters and Van Westen, 1996). It is considered approach to landslide hazard zonation as it identifies the spatial distribution and locations of different types of landslides. However, a substantial limitation of this method is its failure to estimate temporal deviations in landslide distribution. Landslides that happened before the imagery was captured may not be accurately represented, introducing unpredictability. To address this shortcoming, multi-temporal analyses of aerial photographs should be employed to generate more reliable landslide activity maps (Van Westen, 1993). While this method does not determine the relationship amid landslides and their contributing factors, it can qualitatively explain landslide density and provide a baseline understanding of landslide distribution.

3.5 Preparation of the base map

Thematic maps of the study area were generated on a 1:50,000 scale by using the Survey of India Toposheets (SoI). The SoI toposheets were digitally scanned, saved in Tiff format and imported into ARGIS 10.1 software for this purpose. The geo-references on the scanned toposheets were registered by the ground control points and projected to WGS 1984 UTM 46 datum. From the base maps the basic information namely contours, major roads, rivers, and streams were scanned. The primary goal of the base map preparation is to digitally extract thematic information from the toposheets and satellite data in order to generate several maps on 1:50,000scale.

3.6 Data acquired

Data such as literature, maps, and meteorological information is gathered from various sources during the pre-fieldwork phase. Satellite imagery of the study area were obtained using MIRSAC. These satellite images are geo-referenced, and thematic base maps are prepared using SOI toposheets. Image processing software is utilized for image classification and pre-field analysis through ArcGIS.

Preparation of the following thematic maps (in GIS on scale 1:50000)

(i). Geomorphology & Lineament map.

(ii). Slope, Aspect Map & Contour Map.

(iii). Land use/land cover map

(iv). Drainage map.

In hazard zonation, collecting landslide inventory data is vital. Landslide risk assessment, temporal data and spatial variability such as archived information and image analysis are needed. This data is then converted into grid cells, terrain units, and topographic units and slope units (Reichenbach, et al., 2018; Guzzetti, et al., 1999). The primary objective of combining different data sources is to obtain more accurate results when assessing various environmental issues (Archana and Kausik, 2013). The eight thematic maps created by using the data generated from the satellite imagery and fieldwork.

3.7 Utilization of Geo-spatial technology

"Geospatial technology" refers to the tools and systems used to visualize, measure, and analyse Earth's features, often involving technologies like the Global Positioning System (GPS), Geographic Information System (GIS), and Remote Sensing (RS). These systems were working together in several ways for this research. Below is a summary of the core concepts behind these three components of Geospatial technology. GPS (Global Positioning System) is a radio navigation system that permit operator at ocean and sea, on terrestrial or in the air to control their exact position, time and speed. Operating 24 hours a day in all meteorological conditions' conditions wherever globally. It relies on a network of 24 satellites revolving the Earth at altitudes exceeding 20,000 kilometres. These satellites serve as location points, allowing receivers on the ground to triangulate their position. GPS signals are available to all handlers for free, with no licensing or usage fees. GPS plays a crucial role in geospatial technology as it helps capture the geo-coordinates and elevation of any object on Earth's surface. The primary purpose of the GPS system is to inform users of their current location without any charge. General users typically rely on GPS for positioning and timing in daily activities (Obuhuma and Moturi, 2012; Somewar et al., 2013).

Geographic Information Systems (GIS) are computer-based tools used to gather, store, operate, environmental management and show spatially referenced data. It assists in decision-making across various fields, such as management of environment and spatial forecasting. GIS is a comprehensive, computer-based database management system that holds huge volumes of spatial data laterally with associated feature or non-spatial data. These data are gathered, accessed, processed, and analyzed to address geographical inquiries as needed. GIS technology merges traditional database purposes such as queries and statistical analysis through the distinct aids of map-based visualization and geographic analysis. These features usual GIS separately after other information systems, making it a valuable tool for both government and private organizations in clarification events, forecasting consequences, and development plans (Reddy et al., 2013).

The term "Geographic" refers to the Earth’s surface, "Information" refers to knowledge gained from training, knowledge, or instruction and "System" is a set of cooperating or interconnected elements that form a combined whole. Given the vast amount of data complex in groundwater development, GIS technology has been introduced to manage such data efficiently. This technology has gained immense popularity in recent years, particularly for its applications across various scientific and engineering fields (Hasmadi and Imas, 2010).

Remote sensing involves observing and analyzing the physical features of a specific area by measuring the radiation it reflects or emits from a distance, often using satellites or aircraft. The data collected in remote sensing is obtained by electromagnetic radiation either reflected or emitted from the observed object on the earth surface. Remote sensors, such as cameras or scanners, are used to detect this radiation. Key parameters for interpreting satellite remote sensing data include location, tone/color, size, shape, texture, shadow and pattern. These parameters help describe features like lithology, drainage patterns, and subsurface structures, which can aid in evaluating groundwater conditions in a region.

The various application of Remote sensing imagery includes land-use/cover mapping, agriculture, mapping of soil, forestry, city planning, vegetation dynamics, archeological survey, geomorphological surveying, land cover changes, deforestation, water quality monitoring, and urban development (Shefali, 1998)

These studies use conventional geospatial techniques to produce thematic information, represented as layers. To guarantee the accuracy of data collected via remote sensing, GIS and fine-structured method is vital. Each stage of the plan must follow typical data collection procedures to ensure that both non-spatial and spatial data are consistent during the final product creation. To achieve this, the methodology for the study is prepared into three steps: Pre-field work, Field work and post-field work.

3.8. Pre-field work:

In this phase, data from various sources, including literature, maps, socio-economic statistics, and meteorological information, are gathered. Satellite images of the study area are also obtained and aligned with Survey of India topographical sheets. Base maps for different themes are then developed. Digital classification and pre-field interpretation are performed using the Geographic Information System. Furthermore, contour and slope maps are prepared. Pre-field work maps are printed to use for the field verification.

3.9. Field work:

Field verification and ground data collection is a vital component of remote sensing technology. During field visits, key ground data is collected, and any ambiguous areas on the pre-field work interpreted maps are checked on-site. Certain data such as the locations of springs or groundwater information cannot be obtained from satellite imagery and must be gathered during fieldwork. Soil sampling is collected to signify various physiographic units. A handheld GPS is used to record the geographical locations of areas of interest. Ground truth verification is vital for ensuring the accuracy of remote sensing data. Significant ground data was gathered during the field visit, and problematic areas identified in the pre-field work mapping were verified on the ground.

3.10 Post – field work

After the field verification, the pre-field maps are finalized by making necessary corrections and modifications. The information collected from the field are studied, analyzed and conformation of various features in the field. Finally, the landslide hazard zonation map and also the action plan for mitigation measures for the landslides in the study area are prepared.

The methodology is basically a systematic procedure evolved to assess the landslide susceptibility of the study area by using the remote sensing data and GIS techniques in conjunction with limited field work.

3.11 Slope morphometry

In the slope stability study, the slope angle is regarded one of the most significant parameters (Lee and Min, 2004). Slope in a degree is the controlling factor which determines the pace of slides (Joeli Varo, et al, 2019). Slope angle is one of the key factors in inducing slope instability (Sarkar and Kanungo, 2004). Steeper slopes move landmass faster than landmass on gentle slopes. As the angle of slope rises, the shear stress in soil or other unconsolidated material rises as well. As a result, one of the most crucial parameters for stability is considered as slope morphometry by Lee, et. al., 2004. Using ArcGIS 10.1, the slope angle map was created by using a 30m STRM DEM. The various orientations of the slope angle have an impact on landslide onset (Gupta, et al., 1993).

3.12 Slope aspect

The slope aspect map is being created for the present work to show the connection between aspect facing and the incidence of landslides. The slope aspect map was classified using the STRM DEM and ArcGIS platform's aspect tools.

3.13 Morphometric aspect of slope factors for estimating the Landslide Hazards

STRM 1 Arc Second having 30-meter resolution was obtained from Earth explorer (USGS) which is used to generate elevation, slope and slop aspect and contour.

Landslide hazard is often assessed using elevation. Different environmental factors, such as vegetation and rainfall, may influence slope elevation change. Because it affects the shear pressures occurring on hill slopes, slope angle is often regarded to be one of the most important factors in landslide modelling. In landslide research, slope aspect, which relates to sunshine exposure and drying winds, which influence soil moisture, were also considered significant factors. All of them were discovered to have an impact on the occurrence of landslides.

Natural breaks technique in Arc GIS was used to classify aspect, slope, faults (lineament), and elevation maps into various groups. The road, drainage, faults, Land use/Land cover map, geomorphology, lithology, settlement area and building infrastructures were all digitized based on topographic sheet information from the Survey of India and satellite imagery. For representational purposes, the map has been scaled down to 1:25,000scale. The proximity of faults was created by using the 50-m buffer zone. For this research, a lithological map of the study area was created. The lithological map's vector layer was transformed to a raster layer for interoperability with another raster as required by the weighted overlay tool in the ArcGIS software.

CHAPTER - IV GEOLOGICAL SETTING AND LANDSLIDES

4.1 Regional Geology and Tectonics

The north-eastern region of the Indian subcontinent, including the state of Mizoram is an actively deforming transgressional plate boundary. This area, characterized by a fold-thrust belt, is commonly known as the Indo-Burmese Fold-Thrust Belt or the Arakan-Yoma region (Gannser, 1964; Brunnschweiler, I974). In fact, the Hills of Mizoram State are located laterally the central sector of this arcuate, westward-convex deformed fold belt, where geomorphic, geologic, and tectonic relationships suggest that the Indo-Burmese thrust belt has undergone its greatest amount of westward tectonic transport relative to the Indian subcontinent (Kshetrimayum, et al., 2024; Brunnschweiler, 1974). In addition, satellite image interpretation and published tectonic maps of the Indo-Burmese thrust belt suggest that the central Mizoram hills are located just to the west of a structural transition zone between the internal sectors of the thrust belt. Where structural systems are defined by stacked thrust sheets transported along the original low-angle thrust faults, and a "foreland' fold belt defined by detachment tectonics and associated fold-trains and fault-propagation folds (Pivnik, et al., 1998). While it is beyond the scope of the present study to fully determine the structural and tectonic relationships between the central fold-belt of the Mizoram Hills and the entire Indo-Burmese collision zone, it is nonetheless useful to place the Mizoram Hills, and the structural systems within the overall structural/tectonic context of the actively deforming, eastern plate margin to the Indian subcontinent.

The northeastern Indian subcontinent and associated orogenic systems can be divided into several distinct tectonic zones, each defined by its own structural architecture, styles, and evolution. Tectonic zones identified within northeastern India include:

(1) The Eastern Himalayan orogenic belt, located north of the Brahmaputra valley.

(2) The Nagaland fold-thrust belt, which defines the northern sector of the Indo-Burmese orogenic belt.

(3) The Brahmaputra foreland/ inter montane basin that separates the Himalayan and Nagaland fold-thrust belts.

(4) The Chittagong-Mizoram-Tripura fold-thrust belt, which defines the southern sector of the Indo-Burmese ranges.

(5) The Surma Basin, an actively subsiding foreland basin to the Chittagong-Mizoram-Tripura fold-thrust belt.

(6) The Shillong Plateau, a large-scale basement uplift that presently separates the Brahmaputra foreland basin to the north from the Surma Basin to the south.

Northern the Brahmaputra Valley, the Eastern Himalaya define the complexly deformed northern margin to the Indian subcontinent that has undergone several hundred kilometres of tectonic shortening since the early collision between India and Eurasia in the Eocene (Le Fort, 1989; Schelling and Arita, 1991; Schelling, 1992). Tectonic shortening of the Himalaya, south of the Indus-Tsangpo suture which defines the actual plate margin between India plate and Eurasia plate has been accommodated through the development of basement-rooted thrust faults that have involved mid-crustal levels of the Indian continent, as well as shallower level detachment surfaces south of the Main Boundary Thrust (Gansser, 1964; Schelling and Arita, 1991; Schelling 1992). Within the northeastern sector of the Himalaya, between Sikkim and the Mishmi Hills of eastern Arunachal Pradesh, the frontal thrust sheets of the Himalayan thrust belt (the Sub-Himalaya), which involve deformation of only the syn-tectonic sedimentary rocks belonging to the Miocene-Pliocene Siwalik Group are restricted to an extremely attenuated zone of only several kilometers width (Gansser, 1964). Therefore, within the northeastern Indian subcontinent, surface exposures of the Higher and Lesser Himalayan crystalline sequences are presently located within only several kilometers of the active Himalayan (Brahmaputra) foreland basin (Gansser, 1964; Wadia, 1979). The eastern margin of the Indian subcontinent is demarcated by the Indo-Burmese ranges and the Indo-Burmese or Arakan Yoma-Naga thrust belt (Figures 2.1 and 2.2). The Indo-Burmese fold-thrust belt is bounded by the Central (Irawaddy) Basin of Myanmar (Burma) to the east (Le Dain, *et al*, 1984; Pivnik, *et al*., 1998) and by the Brahmaputra basin, Surma basin, and Bay of Bengal basin to the west. While the Central Basin of Burma is characterized by a strike-slip tectonic regime, the

Brahmaputra and Surma Basins are actively subsiding foreland basins separating the Indo-Burmese thrust belt from the Brahmaputra basin, the continental arch to the north and the Indian craton of Bangladesh to the south, respectively. In the South of Bangladesh, however, the Bay of Bengal is underlain by oceanic or transitional continental crust that is presently being sub ducted beneath the southern Indo-Burmese ranges of Arakan (Hamilton, 1979; Ni, et al, 1989; Chen and Molnar, 1990). The Naga fold-thrust belt, which defines the northern sector of the Indo-Burmese ranges, is characterized by stacked, west-northwest-convergent thrust sheets that include ophiolites and related mélange along the more interior thrust sheets and progressively younger, Tertiary stratigraphic sequences towards the foreland basin (Brunnschweiler, 1974; Das Gupta and Biswas, 2000; Kent, et al., 2002).The Surma Basin is a Neogene outer arc basin that is a tertiary sub-basin of the larger Bengal Basin (Ferdous and Renaut, 1996; Mannan, 2002). It is distinguished by alternating arenaceous and argillaceous rhythmites, which indicate epeirogenic activity during deposition (Sarkar and Nandy, 1976). The Surma river in Sylhet, Bangladesh, inspired by Evans (1932) to coin the phrase "Surma Series" (Dasgupta, 1982). The basin is having the en echelon regional anticlinal ridges and synclinal troughs oriented north-south (N15°E to S15°W). The Indian plate tilted and subducted beneath the Burmese plate has created an accretionary prism complex that drifts westward. According to Ganguly (1983), the Kaladan fault, the Neogene Surma Basin to the east, while the post-Barail unconformity borders it. The northeast-southwest Disang thrust and the east-west trending Dauki fault delineate its northern and northeastern boundaries, respectively. The basin's northwest boundary is the NE-SW Sylhet fault, sometimes referred to as the "Hail-Hakula" lineament (Nandy et al., 1983; Ganguly, 1983). The basin stretches south to Myanmar's Arakan coast, and the Barisal-Chandpur High to the southwest (Sengupta, 1966). A north-south fold belt with a westerly convexity, roughly 550 km long and up to 200 km wide is formed inside this enormous region by the Surma Group and newer deposits. The Surma Basin includes sections of Assam, such as the districts of Cachar and Karimganj, Tripura, Mizoram, the western portion of Manipur, Bangladesh's Sylhet and Chittagong districts, and the Arakan coastal region of Myanmar.

It faces the Indo-Myanmar mobile belt have heavily faulted and folded Palaeogene outer arc segment to the east. The Bengal Basin with its homoclinal, slightly descending, alluvium-covered Tertiary sedimentary layers, emerges from the basin toward the west (Nandy, 1972). The "bell-shaped" geometry of the basin is characterized by a continuous paleo-slope that runs south and southwest, joining the open sea in the south.

The Bhuban and Bokabil Formations in the Surma Group is the main exposed lithological units. Based on the sequence of superposition, physical characteristics, and lithological features, the Bhuban Formation is further divided into the Lower, Middle, and Upper Bhuban Formations.

4.2 Surma Group

The Bhuban and Bokabil Formations are the major exposed lithological units in the basin (Evans, 1964). A further division of the Bhuban Formation into the Lower, Middle, and Upper Bhuban Formations is based on the order of superposition, physical characteristics, and lithological assemblages.

Table 4.1. Generalized stratigraphic succession of Mizoram (After Karunakaran, 1974; Ganju, 1975; Tiwari and Kachhara, 2003 &Mandokar, 2000; Duhawma, et. al., 2016; Barman and Rao, 2021).

<table>
<tr><th>Age</th><th colspan="2">Group / Formation</th><th>Thickness</th><th>Gross Lithology</th><th>Depositional Environment</th></tr>
<tr><td>Recent</td><td colspan="2">-</td><td>-</td><td>Gravel, silts and clays</td><td>Fluvial and alluvial</td></tr>
<tr><td colspan="6">------------------Unconformity-------------------</td></tr>
<tr><td>Early Pliocene to Late Miocene</td><td colspan="2">Tipam</td><td>+ 900 m.</td><td>Friable sandstone with occasional clay bands</td><td>Fluvial</td></tr>
<tr><td colspan="6">------------------Conformable and transitional contact -------------------</td></tr>
<tr><td rowspan="2">Miocene</td><td rowspan="2">S</td><td>B o k a b i l</td><td>+ 950 m.</td><td>Shale, siltstone and sandstone</td><td>Shallow marine</td></tr>
<tr><td colspan="4">------------------Conformable and transitional contact -------------------</td></tr>
</table>

To Upper Oligocene	URMA	BHUBAN	Upper (+1100 m.)	Arenaceous predominating with sandstone, shale and siltstone	Shallow marine, near shore to lagoonal
			----------Conformable and transitional contact --------		
			Middle (+1000 m.)	Argillaceous predominating with shale alterations and sandstone	Deltaic
			--------Conformable and transitional contact --------		
			Lower (+900 m.)	Arenaceous predominating with sandstone, silty shale	Shallow marine
------------------Unconformity obtained by faults-------------------					
Oligocene	Barail		(+ 3000 m.)	Shale, siltstone and sandstone	Shallow marine
---------------- Lower contact not exposed -------------------					

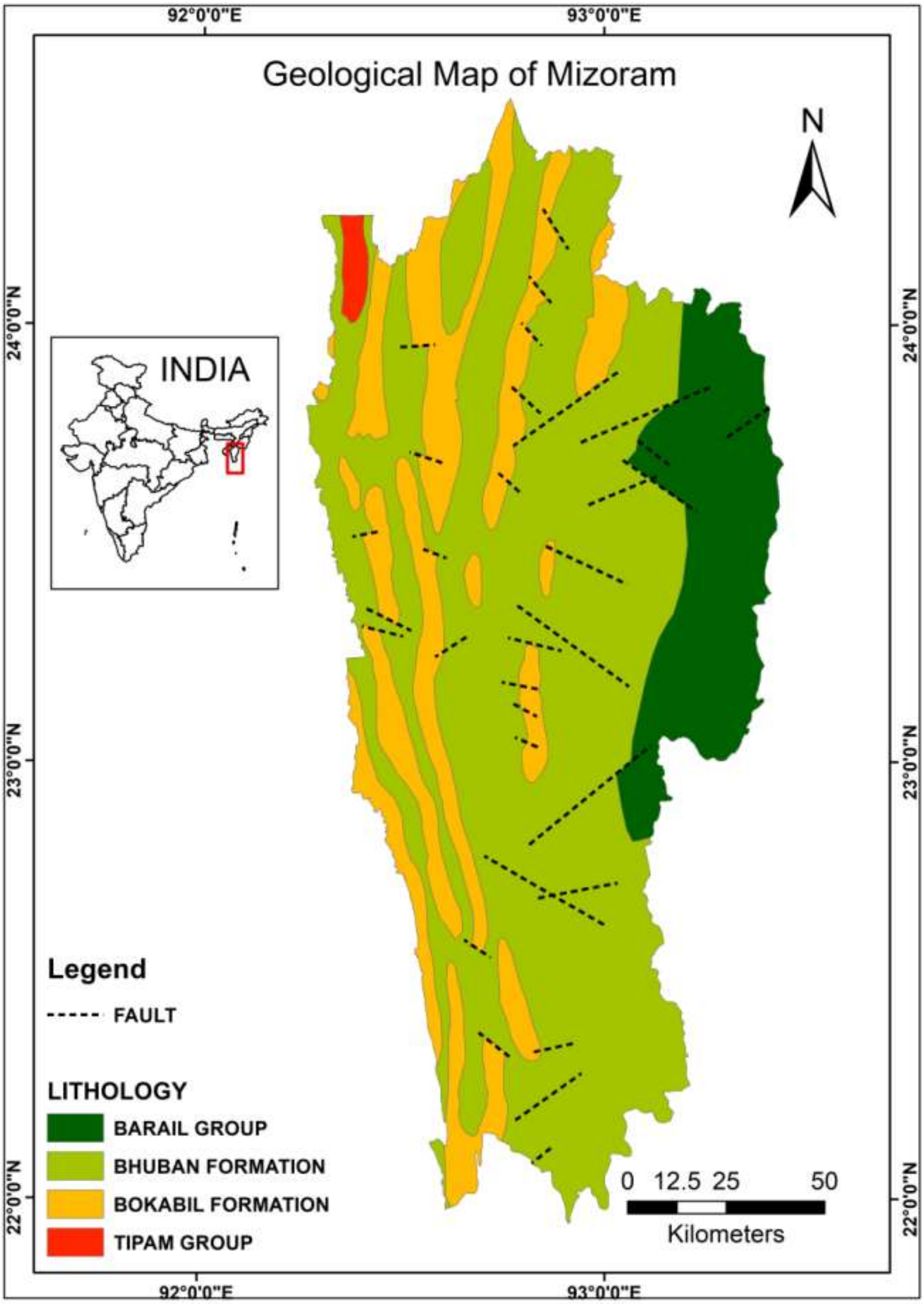

Figure4.1. Geological and broad structures of faults map of Mizoram (After GSI, 2013; Barman, 2021; Barman and Rao, 2021).

4.3 Bhuban formation

The Bhuban formation, which is well-developed in the Mizoram part mostly in the anticlines in the region of the Bhuban range in the western Manipur Hills, where it is found (Nandy, 2017). The siltstone, shale, silt-shale, and muddy sandstone are mixed together in the formation, with argillaceous rocks predominating. The inability to distinguish between finer and coarser clastic sediments leads to intermixtures. Intercalations of sand and shale are common, and the sandstones are generally fine-grained, stiff, and poorly sorted, with frequent changes in facies. There are argillaceous and arenaceous layers that have experienced cyclic sand-shale alteration, which identify the Bhuban group of rocks. The bed of sandstones typically exhibits cross-stratifications and ripple markings.

4.4 Upper Bhuban formation

There is a gradational contact between the Middle and Upper Bhuban Formations are noticed. It is mostly arenaceous, with massive sandstone strata serving as its primary defining feature. These are medium-to-very-fine-grained, hard, compact, and grey to khaki-coloured sandstones. Micaceous sandstone with thin bedding is also found along with siltstone and shale in the lower layers. Weathered sandstones are less compact and have a buff tint. Uneven streaks of lignite-bituminous coal, with or without pyrite, as well as patches and pieces of shale and clay are frequently enclosed by the sandstones. Due to several joint sets, the shale fractures into splintery pieces and is grey to ash-grey in color. The sandstones are poorly sorted in some places with immature to sub-mature, and composed of angular to subangular greywacke sequence. Thinly bedded with bands of alternating siltstone and shale, the fine-grained sandstones show their environment deposition by tidal flats and turbidity currents.

There are also pebble beds, thin bands of calcareous sandstone, and shelly limestone lenses in the Upper Bhuban Formation. The limestone is dark grey, dense, hard, and contains sandstone, shale, pebbles, and broken or whole shells. The spheroidal nodules and calcareous concretions in a range of different sizes and forms are also observed. The Ball-and-pillow structures, lenticular and wavy bedding, cross-stratification, convolute laminations, flute casts, load casts, linguoid ripple marks, and ripple drift laminations are examples of sedimentary features. A white layer of precipitated fine salt is seen along the sandstone's bedding planes. The Pelecypods and Gastropods are among the fossilshellsthat have been found in sandstone and grey shale at various locations. Along and throughout the bedding planes, ichnofossils of all sizes and shapes can also be observed.

4.5 The Middle and Lower Bhuban Formations:

The middle and lower Bhuban formations are having gradational contact with one another. The Middle Bhuban formationhaving the argillaceous dominance and mostly composed of thinly bedded shale, siltstone, and mudstone. The dark grey to greenish-grey shale is somewhat hard, frequently splintery, and frequently stained with iron. The siltstones have a well-laminated, dull, pale-greenish-grey in colour. The thickness of bedding in sandstones is highly variable from place to place and they are sparsely bedded in some places. They are micaceous, hard, fine to extremely fine grained, locally calcareous, and grey or khaki in color. The layers of shale and siltstone alternate with these sandstones. Shale patches and fragments can be found in medium-to fine-grained, softer, friable sandstones with moderately thick to heavy bedding. The other sedimentary features are also observed namely load casts, lenticular and wavy bedding, convolute laminations, micro-cross stratatifications, linguoid ripple marks, and slump structures., The worm burrows of various sizes and shapes can also be observed along and across the bedding planes.

4.6 Lower Bhuban Formation:

The Lower Bhuban Formation is primarily arenaceous and consists of buff-coloured, medium to fine-grained, less compact sandstone and fine to very fine-grained, compact, grey or blue, heavily bedded lithic gravel. The locally calcareous, thin-bedded, hard, compact grey sandstone has fine to extremely fine grained and is poorly sorted. It has a few turbidite characteristics and layers of shale and siltstone that are interlaminated. The shales are compact, dark grey, micaceous, splintery at times, and tinged with iron.

4.7 Bokabil Formation:

The Bokabil formation is named for its type locality near the Bokabil Valley in Hailakandi (Assam) and is widely exposed along the Mizoram syncline. Large facies are characterized by worn patterns and are typically arenaceous, ranging from sandstone to shale. There are several invertebrate fossils in the upper part of these strata. The boulders in this formation are very visible in the northwest part of Mizoram and are of about 950 meters thick sequences (Ganju, 1975).

4.8 Landslide history in the region

The landslides are a frequently occurring in the Mizoram state due to disturbance of steepslope conditions with heavy rainfall. In every year, multiple landslides are reported across the state of Mizoram. The primary causes of slope failure in the region are surface conditions rather than subsurface disturbance or seismic activity. As part of the Himalayan mobile belt, Mizoram experiences neo-tectonic activity, which significantly contributes to slope instability, especially in geologically vulnerable areas such as active fault zones and regions with unconformities (NPDM, 2009). The geology in the state of Mizoramis relatively young, with soft and unstable sedimentary rocks that are highly susceptible to landslides, particularly during heavy rainfall (Lallianthanga *et,al* (2013)). Additionally, the steep slopes, high relief, and poor land use practices have further increased the frequency of landslides.Over the past two decades, several major landslides have been recorded in Aizawl district. In 1992, a landslide at a stone quarry in South Hlimen claimed 66 lives and destroyed 17 houses (Tiwari and Kumar, 1996). In 1994, land subsidence in Aizawl Venglai, Ramthar, and Armed Veng caused severe damage to 65 homes. The following year, a large fracture developed along the Aizawl-Sairang Road in the Hunthar locality (National Highway 54). In May 2011, the Ngaizel landslide blocked the national highway for several days (Verma 2012). Flash floods and landslides triggered by heavy rainfall in June 2017 wreaked havoc in Tlabung, Lunglei district, resulting in at least eight fatalities and six missing persons. On August 27, 2015, intense rainfall and landslides in Aizawl destroyed three homes, damaged 70 graves across two cemeteries, and caused significant damage to four vehicles. In the Chaltlang locality, at least 50 graves were affected. The landslides are also frequently disrupted the National Highway54 hence, cut-off from the district headquarters such as Lunglei, Saiha, Lawngtlai, Serchhip, and Champhai from Aizawl. Throughout 2017, persistent heavy rainfall triggered the landslides and floods across Mizoram, leading to the deaths of at least 12 people and the destruction of 877 structures.

Table.4.2 Major Landslides occurred in the state of Mizoram. (Source: Disaster Management and Rehabilitation Department, Govt. of Mizoram, Aizawl).

Sl. No.	Locality	District	Year
1	**Ramhlun sport complex**	**Aizawl**	**2011**
2	**Rangvamual**	**Aizawl**	**2013**
3	**Armed veng**	**Aizawl**	**2004**
4	**Armed veng**	**Aizawl**	**2013**
5	**Sihpui area**	**Aizawl**	**1983**
6	**Zuangtui**	**Aizawl**	**1987**
7	**Saron Veng**	**Aizawl**	**1993**
8	**Huntharveng**	**Aizawl**	**2016**
9	**Ramhlun sport complex**	**Aizawl**	**2012**
10	**Laipuitlang**	**Aizawl**	**2013**
11	**Hlimen quarry**	**Aizawl**	**1992**
12	**Arm veng**	**Aizawl**	**2016**
13	**Serchhip national high**	**Serchhip**	**2018**
14	**Saikhamkawn**	**Aizawl**	**2008**
15	**Tuikhuahveng**	**Serchhip**	**2018**
16	**College veng**	**Saiha**	**2017**
17	**Durtlang BSUP**	**Aizawl**	**2019**
18	**Saron veng**	**Aizawl**	**2017**
19	**Bazaar veng**	**Mamit**	**2010**
20	**Buarpui road**	**Lunglei**	**Perennial**
21	**Serchhip bazaar**	**Serchhip**	**Perennial**

CHAPTER - V Result and discussion

5.0 Land slide Hazard Zonation and risk assessment

The Task Force on Landslide Hazard Zonation established by the Ministry of Mines, Government of India (2000) that recommended the scales of landslide hazard zonation maps should align with their intended purposes. The task force identified three levels of map scales, each tailored to support sustainable mitigation measures. For example, a map scale where 1 cm represents 25,000 cm on the ground was suggested. Additionally, the task force emphasized that the scales should vary depending on the area being covered. The suggested scale of the mapping for hazard zonation is as follows:

1. Macro scale – 1:50,000 or 1:25,000
2. Meso scale – 1:15,000 or 1:10,000
3. Micro scale – 1:5,000 or 1:2000

In the spatial analysis of landslides, the selecting conditioning factors often referred to as attributes are a crucial stepfor the analyses of landslides. In a GIS environment, these factors are represented through the various thematic layers such as geological, morphometric, hydrological, and environmental parameters. Additionally, the parameters are derived by discrediting, reclassifying, or performing statistical operations on the input data.

Following the field confirmation of critical slope failure areas, the pre-field maps are finalised by assemble the essential improvements and adjustments with field information. The data composed during field surveys are evaluating in detail, and once the primary layers are finalized, derived layers are generated by assemble the primary layers. The spatial coverage is evaluated to determine the area distribution. A comprehensive report is then prepared, which includes a description of the study area, a landslide hazard zonation mapping, and an action plan for mitigating landslide prone area.

The field observations revealed that most of the landslides were shallow translational debris slides or rock slides, with the slip plane depths ranging from 2 to 4 meters. Since the roads are often served as horizontal platforms for debris accumulation, landslides typically occur on the upslope side of the road and have little to no run-out distance. No landslide was observed below the National Highway during the field work. The study area has faced the frequent rock fall throughout the year due to the infrastructure development namely the construction of National Highway. The rock falls those are presented in the study area where the shale and sandstone inter-bedded localities. This type of rock formation is more prone to weathering and erosion. As the shale is weathered more easily than sandstone, this may lead to wedging effect and which fail slowly and led to rock fall. The rock fall area belongs to steep slopes and this area is also undergone regular rock blasting during widening work progress on the National Highway. The blasting effect may have caused fractures and weakening of joint sets present in the area. Hence, the rockfalls occurring throughout the year in different places of the Thingsultliah Rural development block.

The landslides occuralongthe National highway is a common phenomenon during monsoon period in the study area. The rainfall and man made activities are the primary factors for triggering the landslides in the study area. The frequency of slope failures are significantly increasing during the monsoon season, as the heavy precipitation occurs and the other factors like breaking of natural slope, etc. also play a critical role in initiating the landslides.

5.1 Results derived from various Thematic Layers

The analysis and interpretation of various thematic layers generated for the study area were conducted using the satellite image processing through ArcGIS software. The statistical information compiled with the thematic maps finalisation is more useful for delineating the various landslideclasses and the factors affecting landslide frequency in the area.

5.2Geological Factors

Geological rock formations play a significant role in the landslide initiation and the rock unit characteristics in hill regions mostly influence the slope stability. Since the various lithologies of rocksand its structure exhibit more susceptible to geomorphic processes hence, the lithology is a crucial factor in landslide hazard zonation (Pradhan et al., 2007). It serves as a controlling parameter for slope stability, as materials have unique shear strength and permeability properties (Yalcin and Bulut, 2007).

The lithology affects the slope movements, such as rock falls, which are influenced by the factors like rock hardness, fractures, and weathering etc. The lithological characteristics reflect the engineering properties of rocks in the region, including adhesion properties and internal friction angles, which significantly impact the slope stability.

The compositional variations of the different rock types and its structures affecting the strength of the slope materials either positively or negatively (Mersha and Meten, 2020). Compared to softer, weaker rocks, stronger rock units provide more resistance to the driving forces. Furthermore, the rock resistance to weathering and erosion is critical for slope stability.

The study area includes the Tertiary formations of Bhuban and Bokabil from the Surma Group, primarily composed of arenaceous and argillaceous rocks. Two litho-units were identified based on the rock exposures in the study area.

1. Shales (Middle Bhuban formation)

2. Sandstones (Upper Bhuban formation)

The unconsolidated materials like the shale units causing a higher risk of slope failure and are assigned as the high weightage factor. The lithological formations like siltstones and shales are more prone to landslides than the hard, compact sandstone strata.

Based on the lithological mapping in the study area (Fig. 5.1), the shale-siltstones and sandstone-siltstones are the dominant litho-units with shale-siltstones covering an area of about 541.63 sq. km (79.48%) and the sandstone-siltstones occupied by the139.86sq. km (20.52%) area.

Table 5.1.The various lithological units identified in the study area.

Lithology	**Area in Sq. Km.**	**Percentage**
Shales-siltstone belong to the Middle Bhuban Formation	541.63	79.48
Sandstones-Siltstone belong to the Upper Bhuban Formation	139.86	20.52
Total	681.49	100

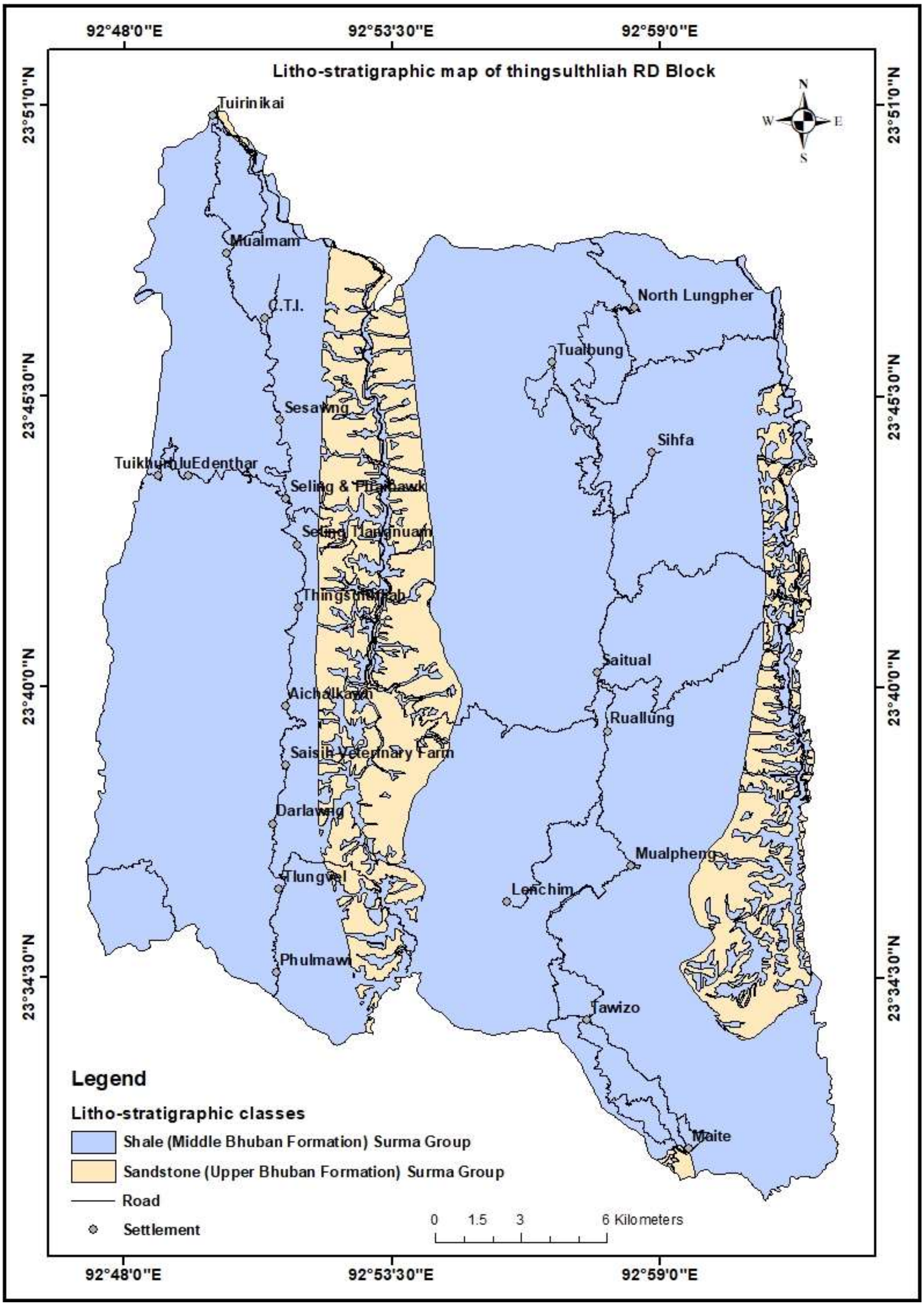

Figure 5.1. Lithological variations in theThingsultliah Rural development block.

5.2.1 Geological structure

Landslide initiation is influenced by the geological rock formations. The rock units of any hill region controlled by the slope failure. Because these fractures reduce rock strength, they are considered susceptible landslide initiating sites (Pradhan and Youssef, 2010). Several landslides have been occurred in the study area due to monsoon rainfall conditions, weak lithology and structures. These structures are the most important variables in determining the landslide risk, and geospatial data may help to identify them (Kanungo et al. 1995; Saha et al. 2005). Remote Sensing data may be used to monitor and quantify geological features such as faults, and fractures, etc. (Kanungo, et al., 1995).

The most significant factors for the Landslide Hazard Zonation (LHZ) are the structure and lithology (Saha, et al., 2002). The geological structures in the study area in the form of anticlines and synclines with lineaments are interpreted from the Remote Sensing imagery (Fig. 5.2). The incidence of landslides is inclined by the geological formations with the geological structures. The discontinuities associated with in-situ rocks across hill slopes, such as, joints, fractures, faults, bedding planes, and foliations, play a crucial role in influencing the slope stability. These geological features often act as planes of weakness, making the slopes more susceptible to landslides and other forms of instability. Slope stability is influenced more by structural discontinuity in relation to slope inclination.

The correlation is sloping direction and discontinuity parallelism, discontinuity of dip and slope dip direction. The rocks exposed in the region are pierced by a number of faults and fractures of variable size and length (MIRSAC, 2006). The areas close to fault zones and other geological features are thought to be more susceptible to landslides.

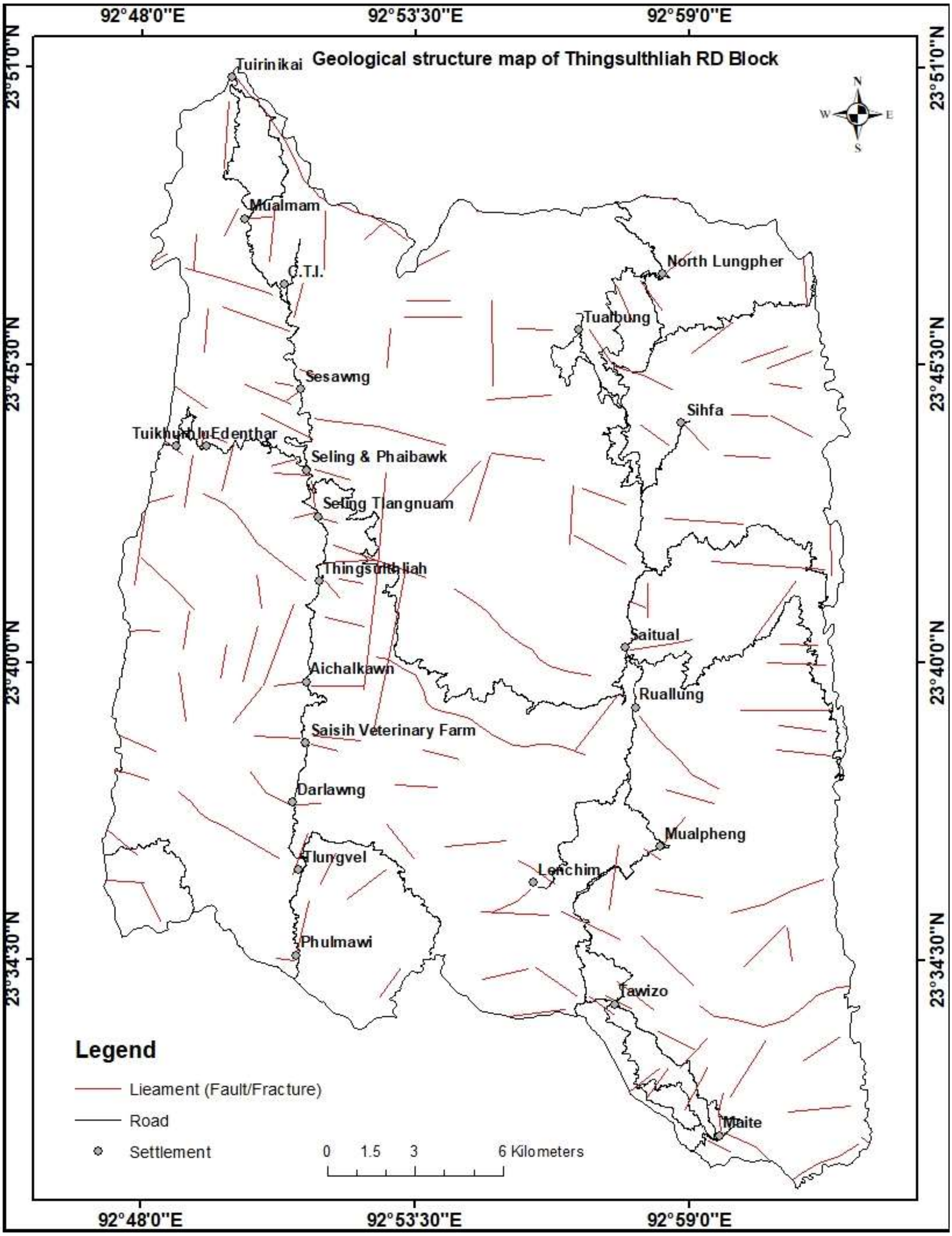

Figure 5.2.The geological structures interpreted from the satellite imagery in the Thingsulthliah Rural Development Block.

5.2.2 Geomorphology

The study area comprises of the structural hill ranges characterized by high dissected undulating terrain, and moderate slopes. Some of the hillocks are having the sharp ridges with steep slopes due to intense dissection, while the others are gently sloping and less dissected, indicating that the topography is still in its early developmental stage. The flat plain areas are very limited, mostly found along the streams and between spurs.

The study area is classified into four geomorphological categories: valley fills, low structural hills, medium dissected structural hills, and high dissected structural hills. Landslides are more prevalent in high-elevation regions compared to low-elevation areas.

The study area is further divided into five geomorphic classes (Fig. 5.3):

- **Highly dissected structural hills**: occupied an area of 56.73%
- **Less dissected structural hills**: occupied an area of 23.05%
- **Moderately dissected areas**: occupied an area of 16.32%
- **Intermontane valleys**: covered an area of 2.3%
- **Fracture valleys**: extends an area of 1.6%

Table 5.2.The various geomorphic units interpreted and its areal distribution in study area.

Geomorphic Units	Geomorphic classes	Area in square kilometres	Percentage
1.	Highly dissected structural hill	386.62	56.73
2.	Less dissected structural hill	157.11	23.05
3.	Moderately Dissected Structural Hill	111.22	16.32
4.	Inter-Montane Valley	15.68	2.3
5.	Fracture Valley	10.85	1.6
	Total	681.49	100

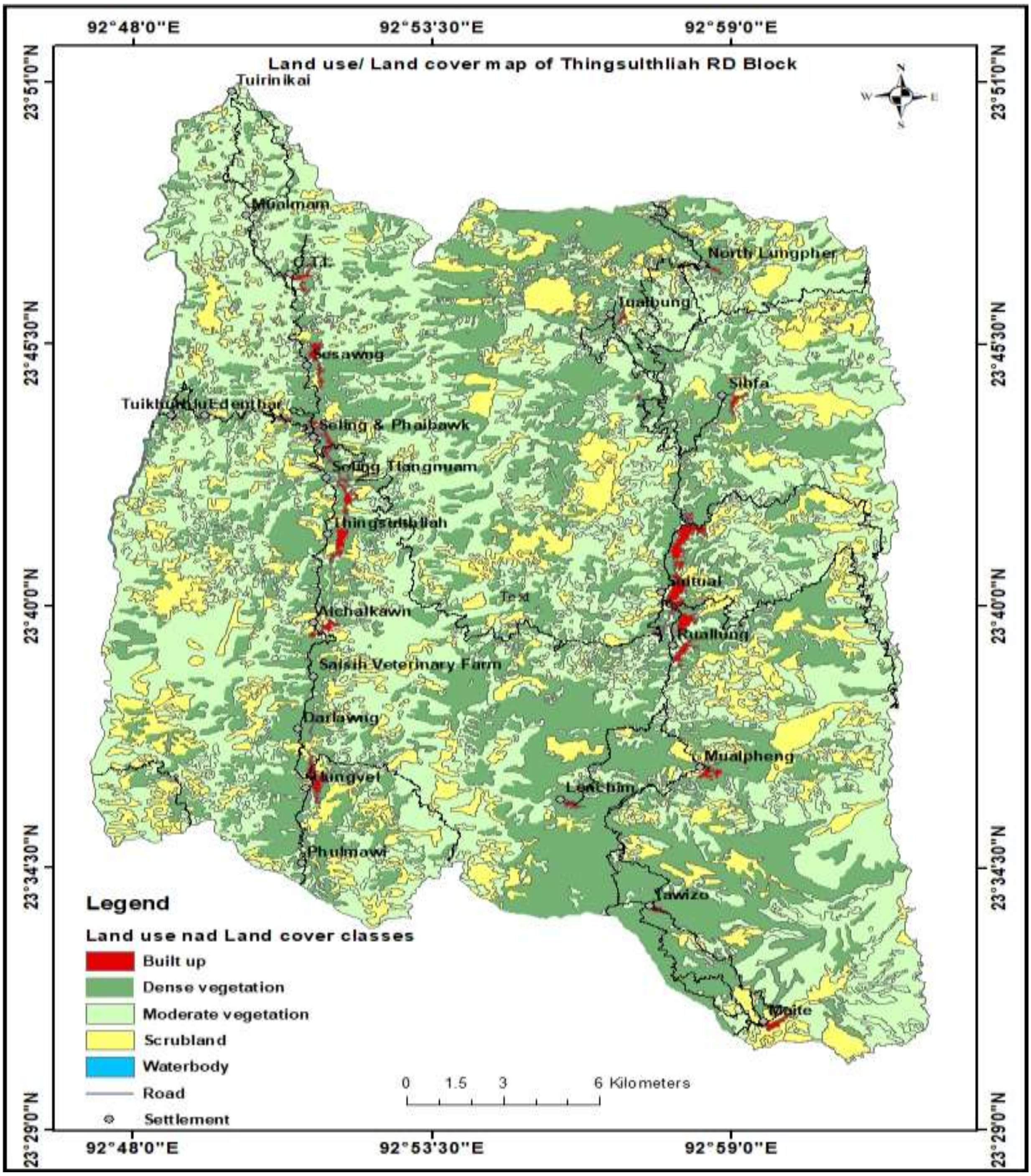

Figure 5.3.The various Geomorphic units identified and mapped in the Thingsulthliah RD rural development block

5.2.3 Relative relief

The study area exhibits diverse levels of relative relief, categorized as high, medium, or local relief (Fig. 5.4). The high relative relief values indicate the increases in steep altitude and may also occur in the fault presence, while the low relief areas signify relatively a more developed topography. Relative relief plays a vital role in landslide hazard zonation, greatly affecting the vulnerability of settlements, transportation networks, and land use (Chandel et al., 2011)

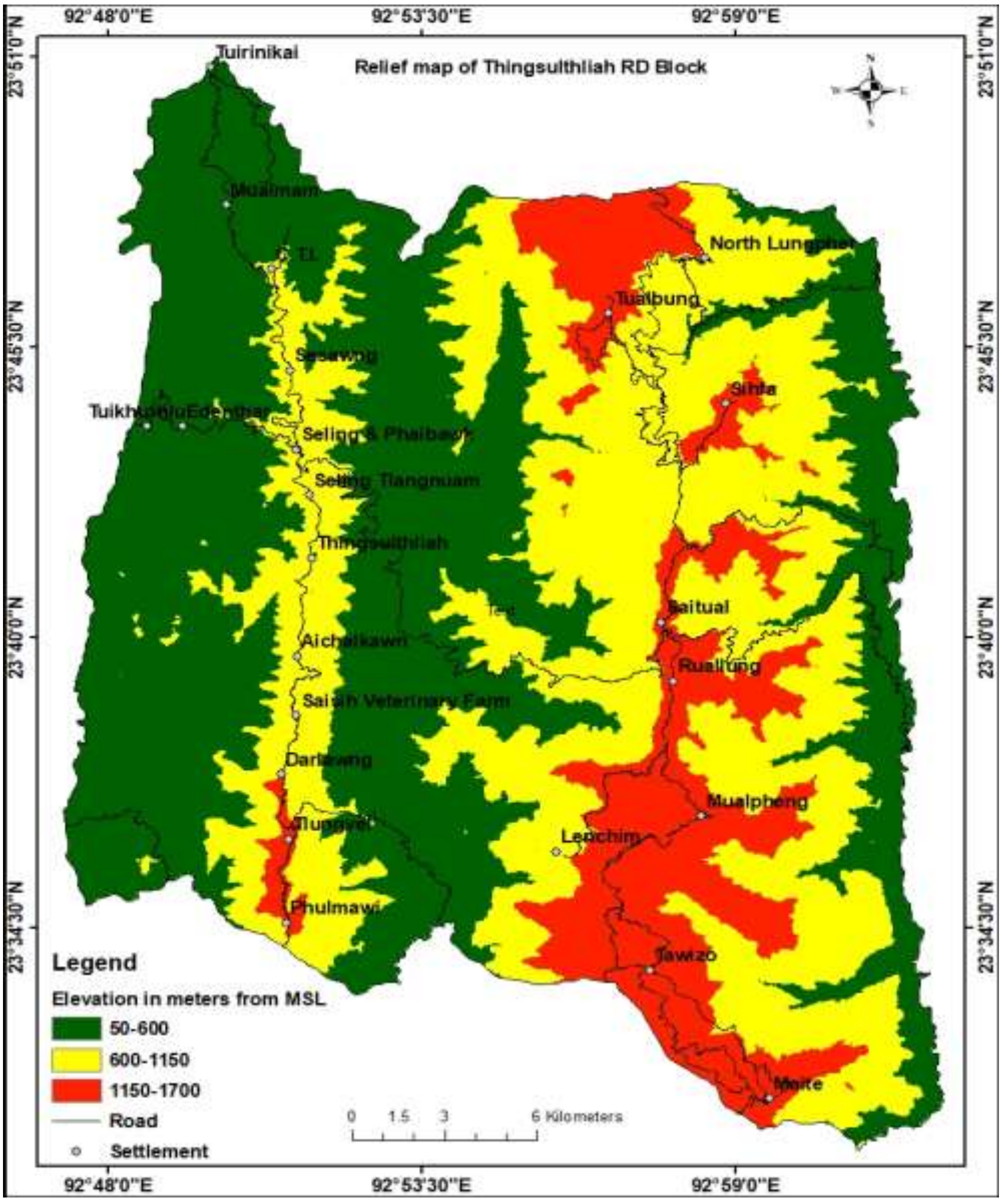

Figure 5.4. Relative relief map of the study area.

The maximum elevation in the study area reaches 1700 meters above mean sea level. The region was divided into High, Moderate, and Low relative relief classes, with elevations ranging from a peak elevation of 1700 meters to a low of 50 meters above sea level. Higher-elevation areas are generally more susceptible to landslides than those at lower elevations (Lee et al., 2004).

Table 5.3. The category wise relative relief distributionin the study area.

Relief Class	Relative relief	Relief Range	Area in square meters	Percentage
1.	High	1150-1700 m	36.96	5.4
2.	Medium	600-1150 m	29.32	42.6
3.	Low	50-600 m	354.21	51.9
-	Total area	-	681.49	100

5.2.4 Slope morphometry

The slope map (Fig. 5.5) of the study area is prepared based on the STRM DEM generated image in the GIS domain for the landslide hazard study. The slope map is categorised into 7 slope classes (Table 5.4). The slope represented in the study area is in degrees and categorised into seven classes as 1. 0°-10°; 2. 10°-20°; 3. 20°-30°; 4. 30°-40°; 5. 40°-50°; 6. 50°-60°; 7. >60°.

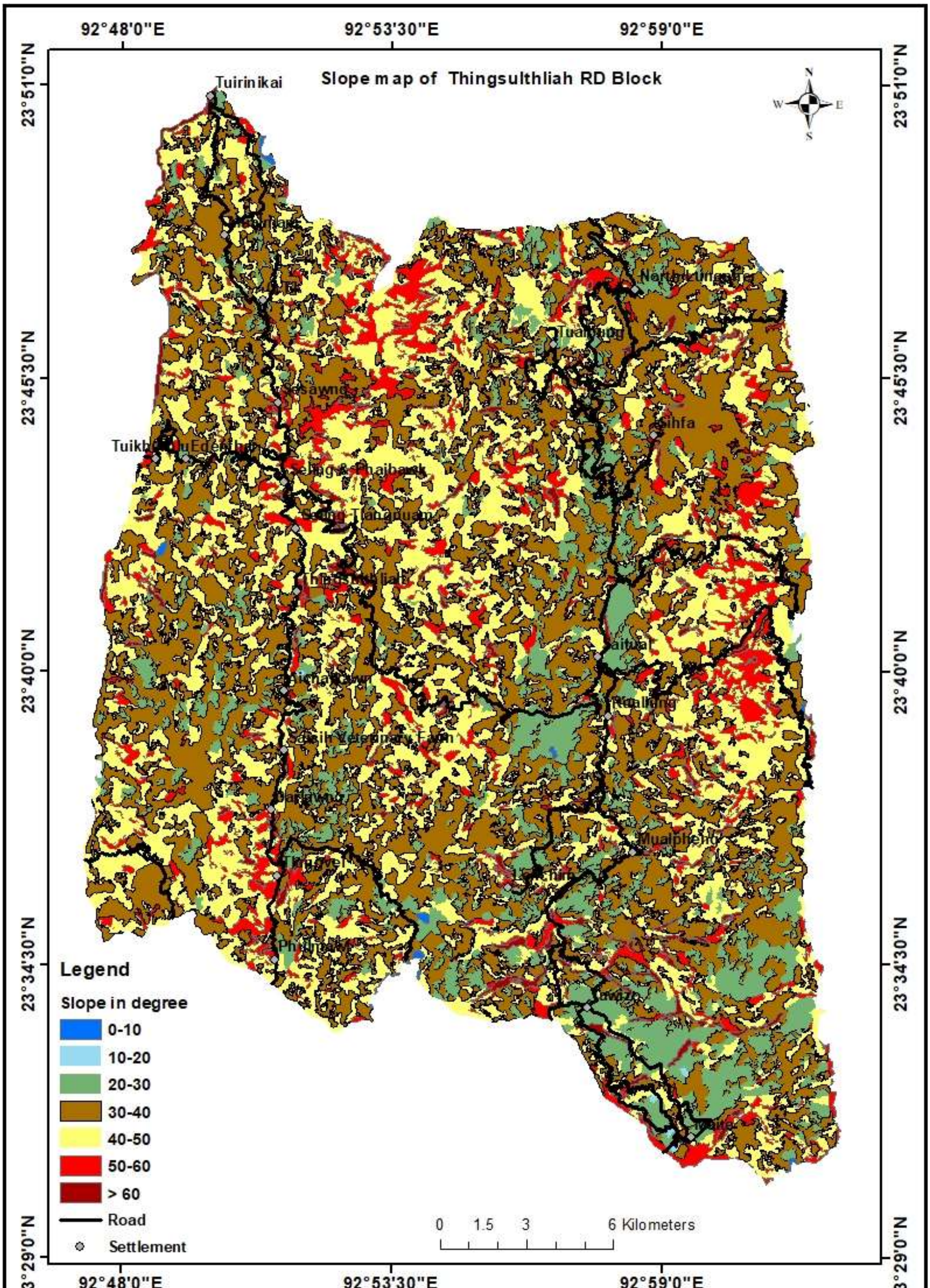

Figure 5.5. The slope map of Thingsulthliah Rural development block.

Table 5.4. The slope classification in the study area.

Slope class	Slope angle	Area in square kilometres	Percentage
1.	0-10	1.88	0.28
2.	10-20	0.38	0.06
3.	20-30	14.16	2.08
4.	30-40	337.56	49.54
5.	40-50	240.14	35.24
6.	50-60	76.03	11.16
7.	>60	11.33	1.66
-	Total Area	681.49	100

5.2.5 Slope Aspect Map

Another key characteristic influencing the landslide events is slope aspect, the same aspect examined by various researchers (Yalcin et al., 2007; Pourghasemi et al., 2013; Ghosh et al., 2014) in different terrain conditions. The slope aspect denotes to the alignment of a slope, typically measured in degrees from 0° to 360°. The aspect map of the study area (Fig. 5.6) was developed through satellite image interpretation. This factor is critical in landslide studies as it governs slope exposure to the sunlight, wind direction, rainfall (saturation levels), and discontinuity conditions (Komac, 2006). The various hydro-meteorological processes, such as sunlight intensity, precipitation, and topographic characteristics, play a role in triggering landslides (Pourghasemi et al., 2013).

The rainfall on a hillside slopesis influenced by its capacity for absorption, which depends on factors such as slope topography, rock permeability, land use, organic matter content, porosity, moisture retention and seasonal climatic variations (Pourghasemi et al., 2013). For example, the south-facing slopes of the Himalayan Mountains receive significantly more rainfall compared to the north-facet slopes (Ghosh et al., 2014). The area coverage for various aspects of slope is provided in Table 5.5.

Table 5.5.The types of slope aspects distribution in the study area.

Aspect	Area in square Kilometre	Percentage
Flat	0.01	0.00
North	39.88	5.85
North east	90.60	13.29
East	92.45	13.57
South east	86.24	12.65
South	72.20	10.59
South West	85.01	12.47
West	91.50	13.43
North west	85.20	12.50
North	38.40	5.63
Total	681.49	100

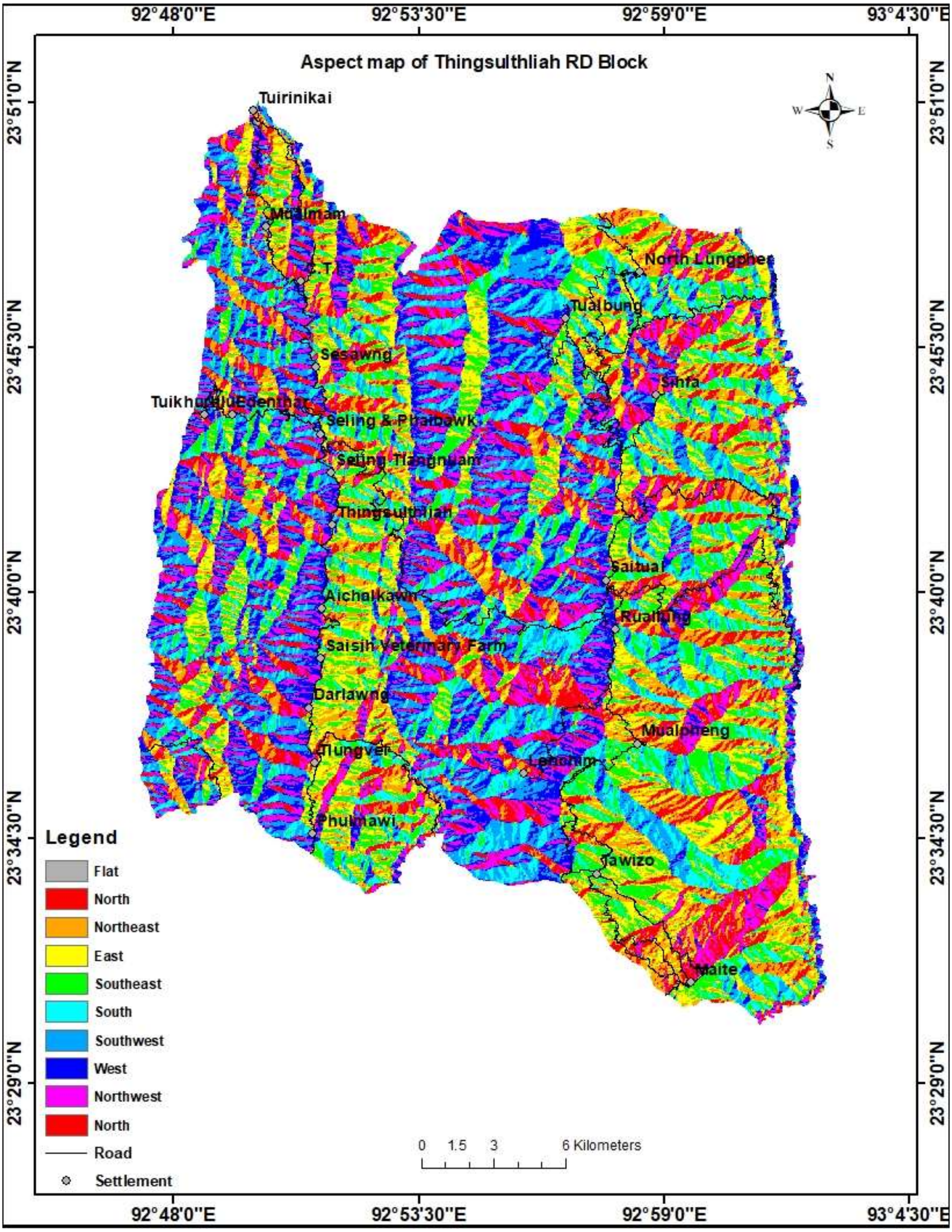

Figure 5.6.The slope aspect map of the Thingsulthliah Rural development block.

5.2.6 Generation of Digital Elevation map

A digital elevation map represents the Earth's surface features using elevation contour lines. The points of equal height above or below a reference level, usually mean sea level, are connected by these imaginary lines. The contour lines generally show that the steepness of slopes, the depth of valleys, and the height of mountains.

On digital elevation maps, a variety of ground characteristics may be observed, which can be divided into the following categories: Contours define relief, which includes mountains, valleys, slopes, and depressions. The hydrography includes the lakes, rivers, streams, marshes, rapids, and falls. The most prevalent kind of vegetation is wooded regions. The digital elevation model (Fig. 5.7) of the study area is prepared based on the SRTM data of 30m interval.

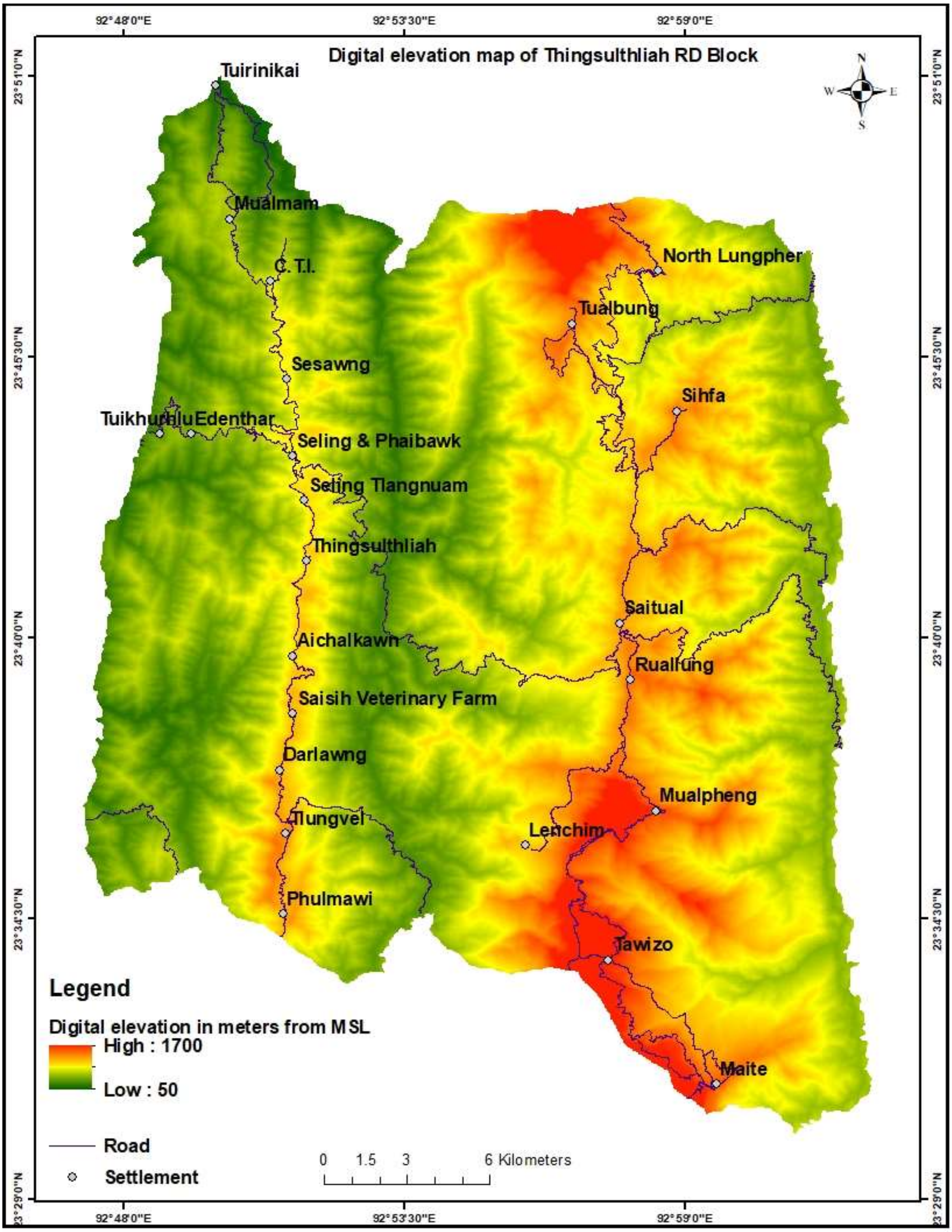

Figure 5.7. The generated Digital elevation model ofThingsulthliah Rural Development Block.

5.2.7 Land use and land cover

Land-use changes are widely recognized as a key factor for influencing the rainfall-induced landslides. Human activities such as Intensive farming, overgrazing, deforestation, and agriculture practices on the steep slopes can be led to slope instability (Glade, 2003).

The land use and land cover (LULC) pattern play a crucial role in maintaining the slope stability. The vegetation is particularly important in preventing slope movement, especially for shallow slip or rupture surfaces. A well-developed root system enhances the shearing resistance of slope material by naturally anchoring it. Additionally, the vegetation helps in reduce the erosion and improves the overall slope stability.

Conversely, unfertile or sparsely vegetated slopes are more susceptible to attrition, increasing the likelihood of slope instability. The long-term vegetative cover is essential for stabilizing the slopes, as plant roots not only reinforce the soil, but also regulate its moisture content by absorbing water for metabolic processes such as photosynthesis and transpiration. This control over moisture content is crucial, even during natural precipitation cycles.

In the study area, hill slopes are composed of overburden materials like colluvium or a weathered mantle of shallow thickness. Dense vegetation or grass cover can mitigate physical weathering and erosion, thereby enhancing slope stability. In contrast, unfertile or sparsely vegetated slopes are more vulnerable to weathering and erosion, increasing the risk of failure. When mapping landslide susceptibility, LULC is a critical factor to consider. The vegetation stabilizes the soil by reinforcing it with the root system, significantly reducing the likelihood of slope failure (Begueria, 2006).

The LULC patterns influence the weathering and erosion rates, making them a crucial factor in slope stability (Anbalagan et al., 2008). Among the various land cover types, built-up areas have been identified as the most prone to landslides, while densely vegetated areas are less vulnerable. In the study region, built-up areas cover only 0.84%, whereas dense vegetation occupies 29.45%, and moderate vegetation covers the largest portion at 53.96% (Fig. 5.8, Table 5.6). Additionally, scrubland accounts for 16.63% of the area, while water bodies make up 0.12%.

Table 5.6.The types of land use and land cover distribution in the study area.

LU/LC Classes	**LU/LC type**	**Area in Square kilometre**	**Percentage**
1.	Built up	5.7	0.84
2.	Dense vegetation	200.71	29.45
3.	Moderate vegetation	360.92	53.96
4.	Scrub land	113.36	16.63
5.	Water body	0.81	0.12
	Total	681.49	100

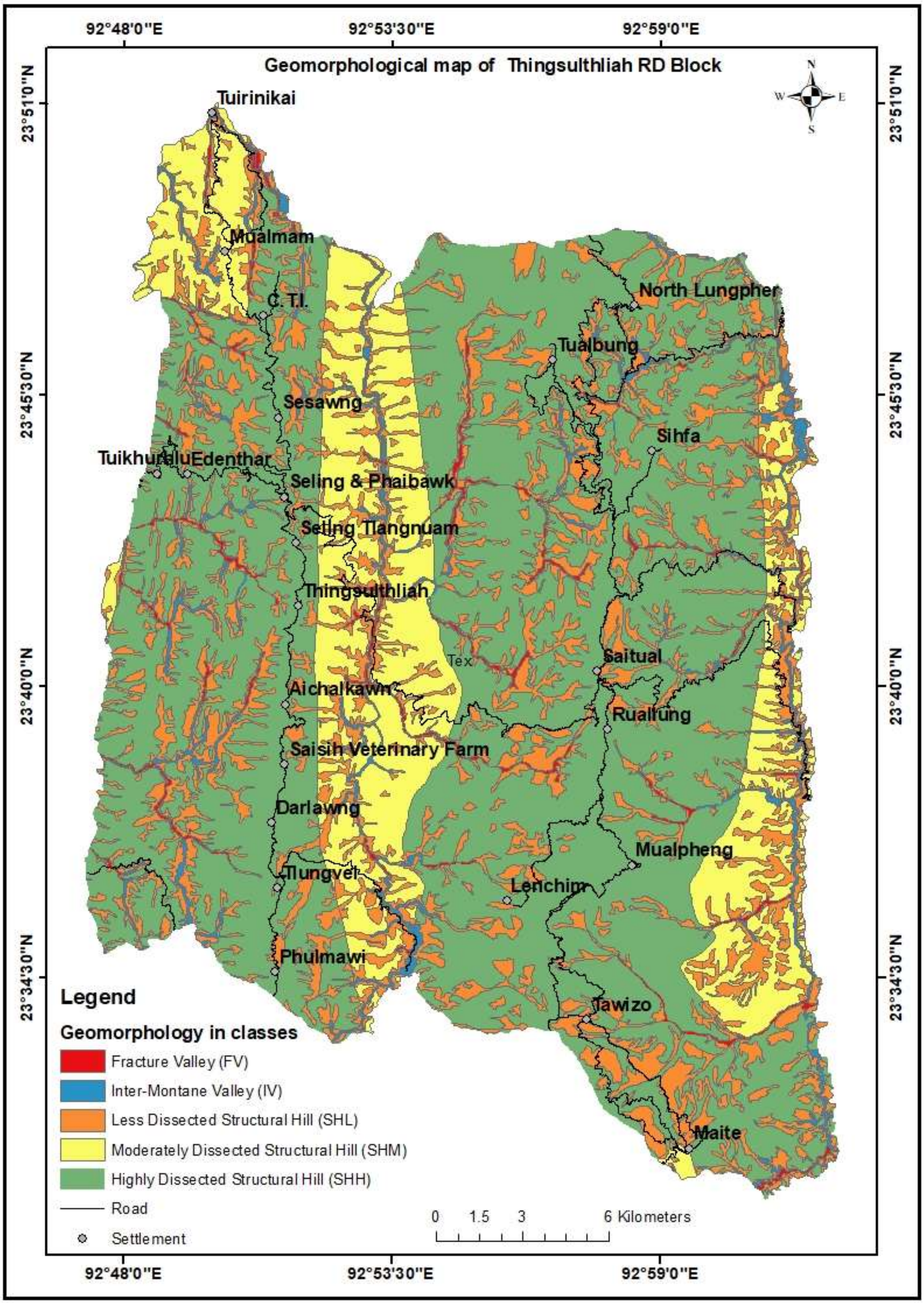

Figure 5.8.The land use and land cover distribution in the study area.

5.2.8 Soil types

Landslides are primarily triggered by the changes in water content and stress within the unsaturated soils. The soil properties, particularly clay content, significantly contribute to these stresses, making areas with clay-rich soils, especially in hilly regions, more vulnerable to landslides.

In the hilly terrains with complex topography, clays play a crucial role in slope failure and landslide occurrences. The predominant soil types in the region include clay loam and sandy loam. Higher elevations are mainly composed of clayey soils, while the low-lying areas mainly consist of sandy loam, influencing the slope stability and landslide susceptibility.

Table 5.7. The distribution of Soil types in the study area.

Soil type	Area in sq.m	Percentage
Clayey loam	353.27	51.83788
Sandy loam	328.22	48.16212
Total	681.49	100

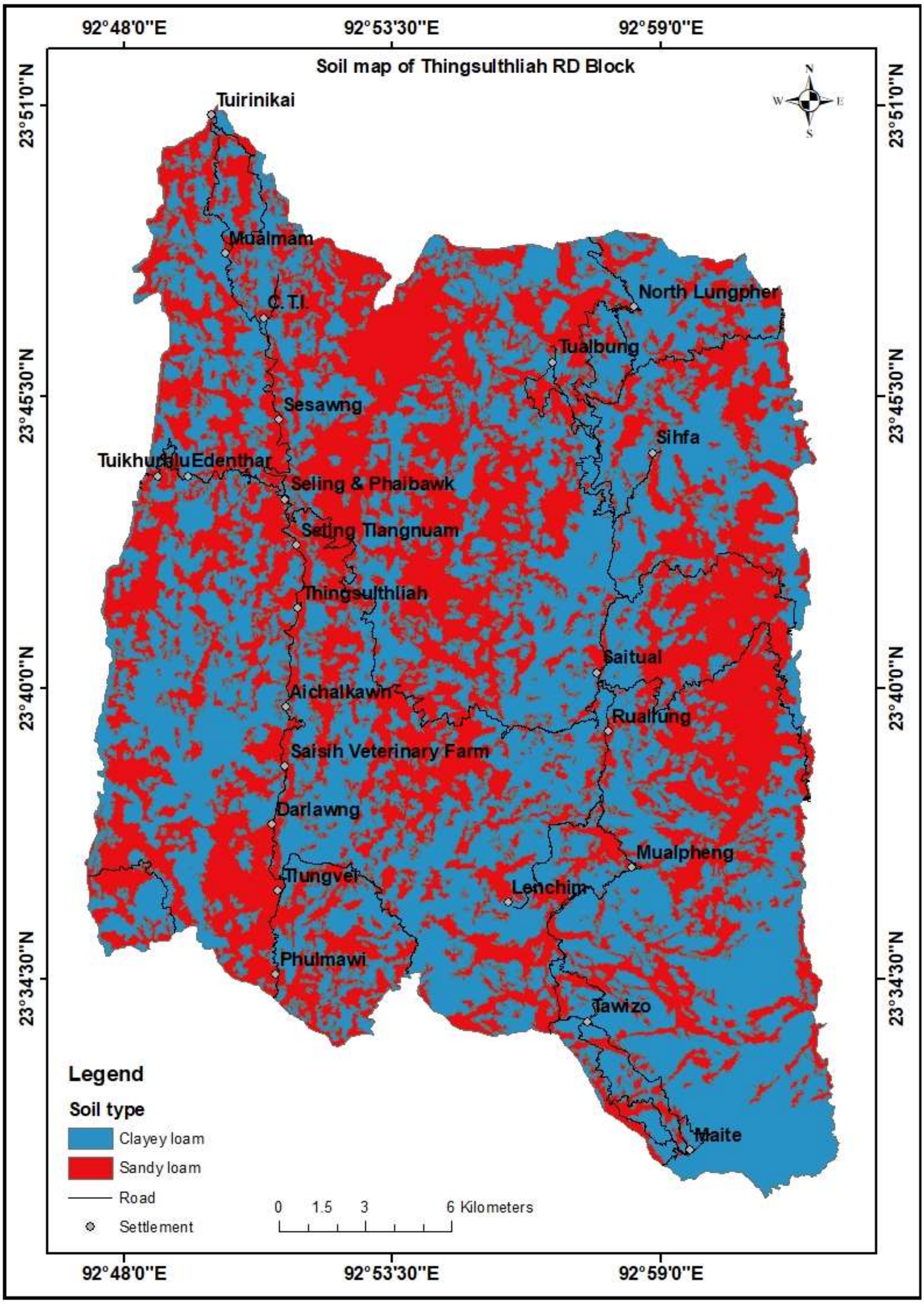

Figure 5.9.The distribution of soil types in the Thingsulthliah Rural Development Block.

5.2.9 Drainage density

The drainage density was initially presented by Horton (1932) as a crucial indicator for evaluating the linear scale of landform components in stream-eroded landscapes. It is determined by separating the drainage density is calculated by dividing the entire area of a drainage basin by the length of all of its rivers and streams. This metric shows how well or sparsely the streams drain in a watershed in relation to the overland flow length.

The higher drainage densities are typically found in areas with rough terrain or high relief than in other basins with comparable features. During rainfall events, drainage density also affects how a river's hydrograph is shaped. A “flashier” hydrograph with a steep falling limb is frequently produced by basins with high drainage densities, suggesting quick runoff and a higher danger of flooding. Furthermore, a high bifurcation ratio, which indicates a higher risk of landslides, is correlated with high drainage density. The higher frequency ratios of the streams are generally found in areas with high or extremely high drainage densities, suggesting a higher risk of landslides. On the other hand, landslides are less likely to occur in areas with low drainage density and a lower frequency ratio.

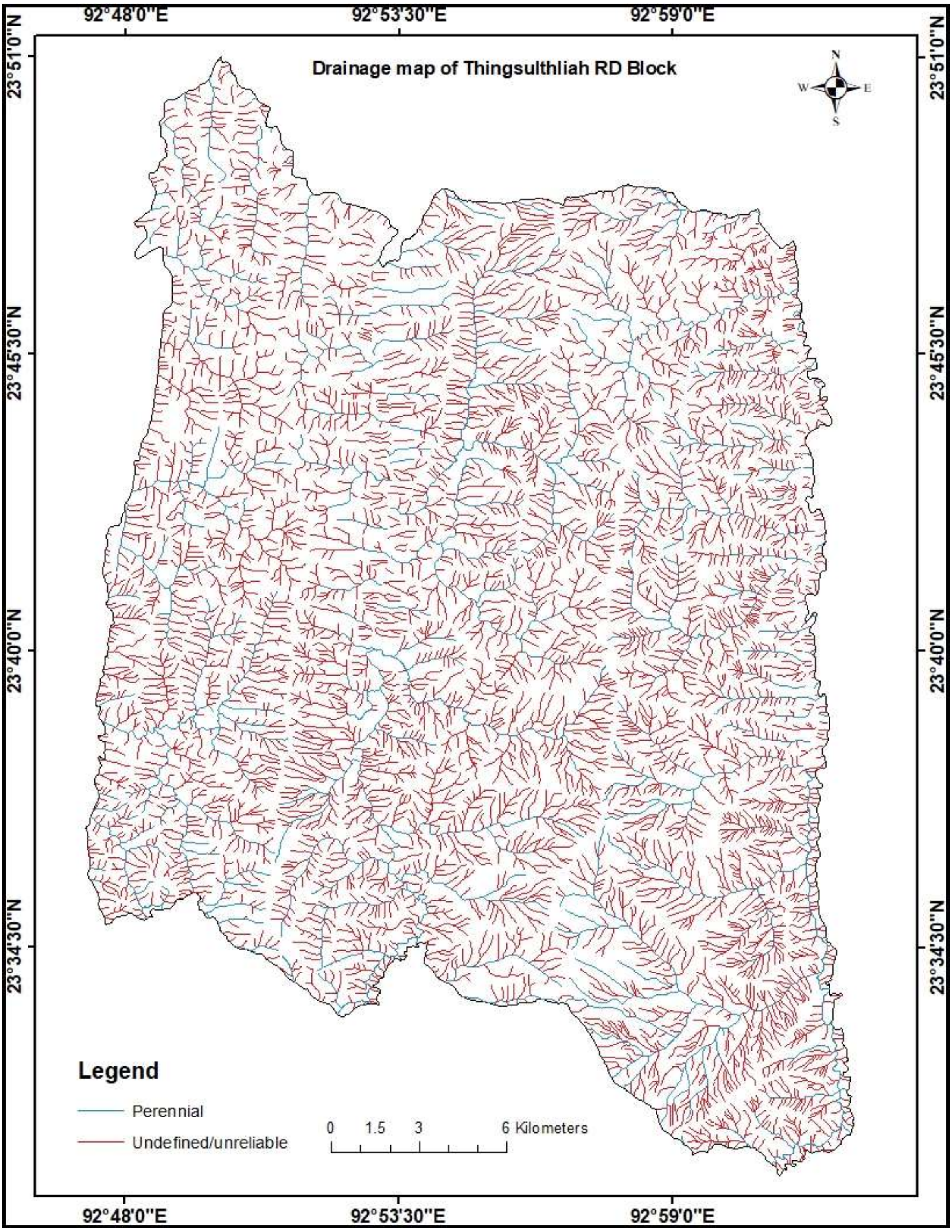

Figure 5.10. The Drainage distribution in the Thingsulthliah Rural Development Block.

5.2.10 Rainfall

The rainfall is the main factor that triggers landslides and is commonly used to predict slope failures. However, the connection between rainfall and landslide occurrences is highly complex. Significant research has been conducted in recent years to develop regional forecasting models for rainfall-induced landslides, yet no universally accepted prediction method exists (Shibiao Bai et al., 2013). Changes in rainfall patterns on fragile hill slopes play a major role in the rising frequency of landslides and associated damage. The increase in total rainfall and the growing unpredictability of heavy showers have heightened concerns about the likelihood of landslides. In this study, rainfall data (2011-2019) for the research area was collected from the Agriculture Department, Government of Mizoram, and analysed using the Inverse Distance weighted (IDW) interpolation tool in ArcGIS.

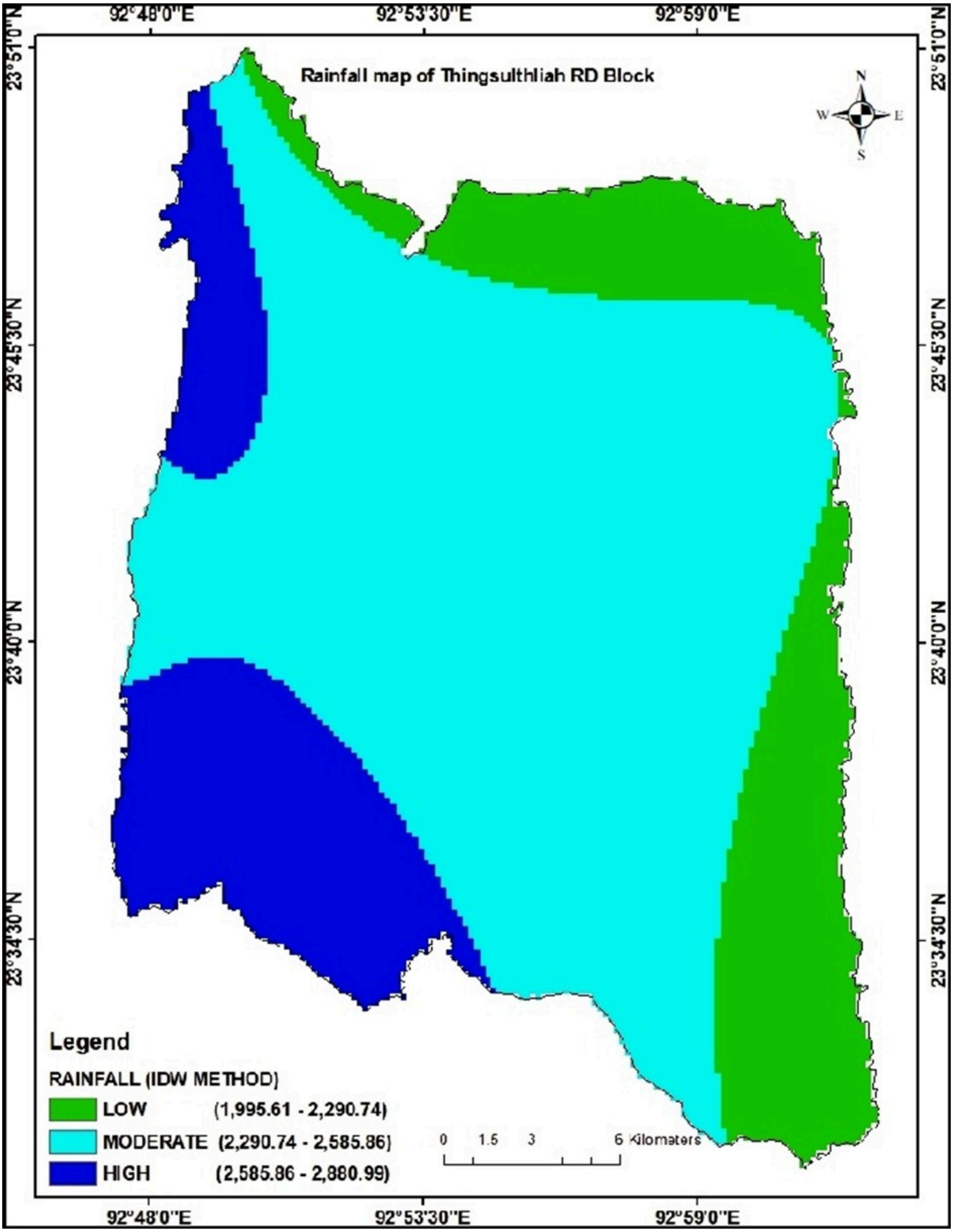

Figure 5.11. The rainfall distribution in the Thingsulthliah Rural Development Block.

Table 5.8. The annual rainfall distribution patterns of Mizoram during 2011-2019

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2011	257	13.5	1467	2508	9347	9648	7963	10679	7064	3313	11.4	0
2012	380	422	438	7516	4924	11081	6000	10485	8747	4893	1483	0
2013	0	52	88	2067	14635.4	9027.2	10142.6	23912.2	10849.8	4287.4	0	0
2014	0	574.1	644.7	1171.2	8343	7750.4	8503.7	7070.5	9982.6	2893.4	123.3	26.7
2015	345.1	222.3	671.7	7158.9	4310.7	7387	11490.4	11349.2	7458.6	4555.7	169.4	36.3
2016	62.9	788.4	2140.6	4394.7	9258.4	10829.9	8221.4	10044.3	10531.7	4557.1	1968.2	0
2017	0	198.8	3511	8488.2	5843.9	14271.5	9521.6	13085.5	8415.9	7342	358.3	1590.2
2018	152	96.4	721.5	2984.3	6978.3	15715.1	9438.2	9500.5	4182.5	3155.1	70	169.8
2019	17.1	1366.3	1165.9	2027.3	4915.8	7011.1	13390	7743.6	6455.8	2269.8	1313	210
Average	134.9	414.9	1205.4	4257.3	7617.4	10302.4	9407.9	11541.1	8187.5	4140.7	610.7	225.9
Max	380	1366.3	3511	8488.2	14635.4	15715.1	13390	23912.2	10849.8	7342	1968.2	1590.2
Min	0	1	88	1171.2	4310.7	7011.1	6000	7070.5	4182.5	2269.8	0	0

In the study area, landslides are primarily caused by geo-environmental factors as relative relief, soil, rainfall, drainage density, aspect, lithology, geological structure, slope morphometry and land use/land cover. These characteristics fall into different groups and are important considerations for hazard zonation. To ascertain how each class under these characteristics relates to landslide susceptibility, a thorough analysis is conducted.

Each class is given a weightage value according to how much of an impact that they have on the occurrence of landslides. The higher the weightage values indicate greater vulnerability of landslides, while the lower values indicate negligible impact. The expert knowledge and previous occurrences of landslides in the study area serve as guidance for the assessment procedure. A Landslide Hazard Zonation map is then created by integrating and analysing all of the thematic layers in a GIS environment using ARCINFO software (Fig. 5.8).

The present study utilises the stability of landslides assessment system created by Joyce and Evans (1976) as well as the weightage assignment methodology proposed by the National Remote Sensing Agency (NRSA, 2001). As shown in Table 5.9 these combined methods offer a thorough framework for evaluating the landslide risk.

Table 5.9. The weightage factors assigned to the various thematic layers generated for demarcating the landslide hazard zonation in the study area.

Sl. No.	FACTOR	Rank in percentage	CLASS	WEIGHT
1	Slope (In degree)	25	0-10 10-20 20-30 30-40 40-50 50-60 >60	1 2 4 5 7 8 8
2	Soil	14	Clayey loam Sandy loam	8 4
3	Lithology	12	Shale-siltstone Sandstone-siltstone	8 4
4	Geomorphology	10	Highly Dissected Structural Hill Less Dissected Structural Hill Moderately Dissected Structural hill Inter-Montane Valley Fracture Valley	7 4 3 4 5
5	Rainfall	9	Low Moderate High	2 4 6
6	LULC	9	Dense Vegetation Moderate Vegetation Built up Scrubland Water Body	7 3 4 7 1
7	Drainage density	6	Perennial Non-Perennial	3 5
8	Lineament	6	Fault or Fracture	8
9	Relative relief (in meter)	5	50-600 600-1150 1150-1700	4 5 7
10	Aspect	4	Very low Low moderate High Very high	1 2 4 5 7

The Thingsulthliah Rural Development Block area landslide inventory map (Fig. 5.9) has generated and the landslides field information also collected in the form of field photographs presented along with the name of the nearest settlements of 4 village locations in the study area (Table 5.8). The five landslides identified in the field and the information of its locations are presented in the form of photographs (Plates from 1 to 7) with GPS measurements also mentioned in the Table 5.10.

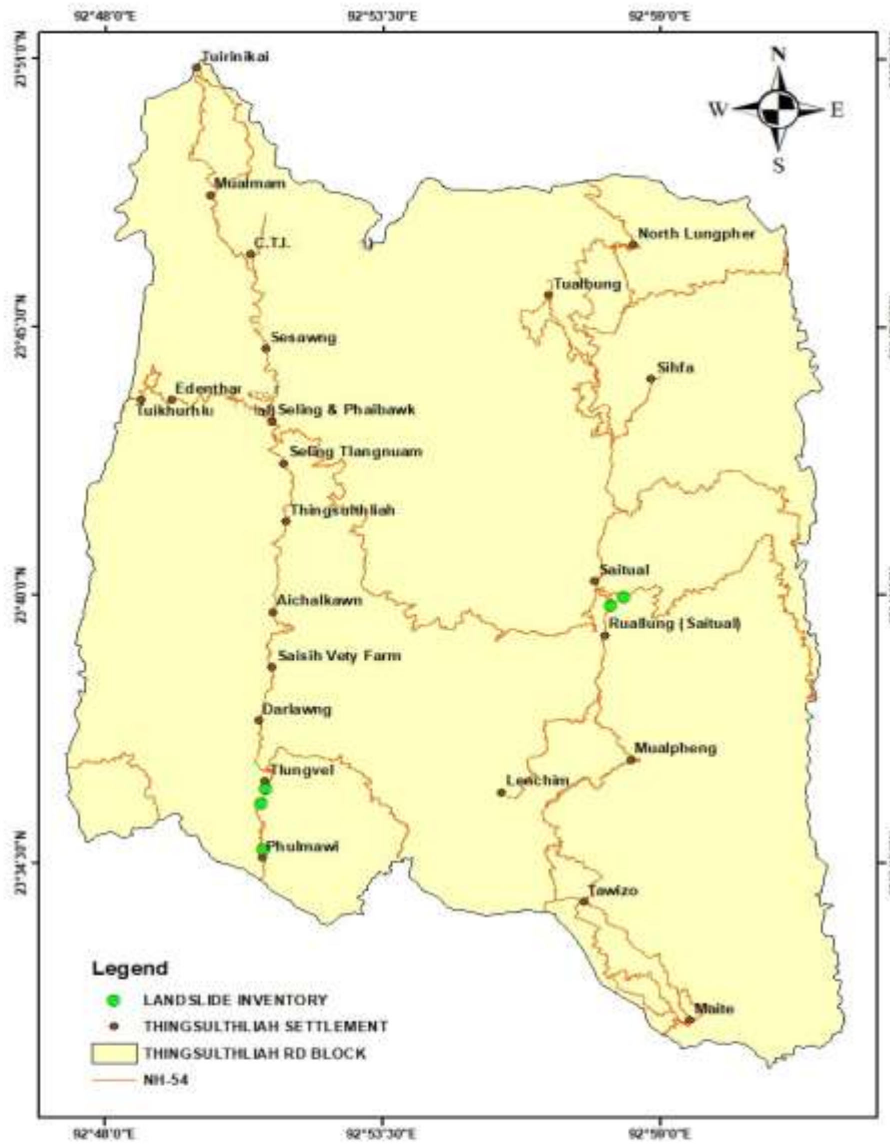

Figure 5.12. Landslides inventory locations in the study area belong to the Thingsulthliah Rural Development Block.

Table 5.10. The field investigation of landslides with the GPS locations of different villages in the ThingsulthliahRural Development Block.

Landslide inventory	
1. Phulmawi village area	**Elevation**
1) 92°51'2.85"E 23°34'8.80"N	1096m
2. **Tlungvel village area (2)**	
1) 92°51'2.52"E 23°35'24.21"N	1215m
2) 92°51'6.94"E 23°35'50.04"N	1217m
3. **Rulchawm village area (1)**	
1) 92°58'5.74"E 23°39'45.20"N	1178m
4. **Keifang village area (1)**	
1) 92°58'38.91"E 23°40'8.06"N	1035m

CHAPTER - VI Landslide Hazard Zonation

6.1. Landslide Hazard Zonation

By integrating all the relevant thematic parameters (Table 6.1) and assigning the different weightage values to each, the final Landslide Hazard Zonation (LHZ) map is developed. This map classifies the study area into four landslide hazard zones: namely 'Low,' 'Moderate', 'High' and 'Very high". The output hazard zonation map is produced at a scale of 1:25,000. The classifications of various hazard zones are described below:

6.1.1. Very High landslide Hazard Zone

This zone is geologically unstable and highly prone to landslides, particularly during and after heavy rainfall. The area consists of steep slopes with loose, unconsolidated materials and includes the locations with visible signs of past or ongoing landslides. Additionally, the road cuttings and human interventions contribute to its instability. Due to the high susceptibility to landslides, human activities in this zone should be strictly avoided. The expansion of the settlements and developmental projects are discouraged, and it is recommended that the area be left undisturbed to grow the natural vegetation for sustaining the long-term stability. This zone covers an area of 79.10 sq.km, which approximately 11.66% of the total study area.

6.1.2 High landslide hazard zone

This zone encompasses areas where the risk of landslides is significant due to the presence of weathered rock and loose soil debris. The terrain consists of steep slopes that are particularly vulnerable to landslides when disturbed. Many existing landslides are located within this category. Additionally, the areas, where rocks dip in the same direction as the slope (often exceeding 45 degrees) are included in this zone, making them prone to sliding. Intense rainfall can further exacerbate instability in this zone.

The geological features such as lineaments, fault planes, and fractured zones traverse this category, contributing to its susceptibility. Areas undergoing the continuous erosion by streams, due to the soft nature of the lithology and loose overlying materials are also part of this zone. The vegetation in this zone is generally sparse or may be absent. The High Hazard Zone is widely distributed across the study area, which covers an area of 488.36 sq. km and constituting the 71.66% of the hazard zone, making up more than half of the total study area.

Table 6.1. The Selected landslide causative factors and their integration in the landslide occurrences (Modified after Suvam Das et al., 2024).

Causative References Factors	**Rationale for selection**
Slope	Significantly controls the rate of shear forces, and directly affects the Bera, et al. 2021surface and sub-surface flows. Thereby, governs the landslide process.
Aspect	Affects the local climatic (precipitation amount, sunlight exposure), and Atkinson and Density of vegetation, which further controls the landslide processes. Massari, 2011
Elevation	Represents the height of the terrain and controls the working intensity of Nath, et al. gravity-driven forces such as erosion and deposition. The magnitude of 2022 elevation also controls the climatic condition and is found a significant factor affecting the landslides.
Relative relief	Measures the elevation contrast per unit area. Generally, high relative Das et al. relief areas are often subjected to intense geomorphic activities that favour 2022the land slide process.
Drainage density	Indicates drainage concentration in an area. High drainage density supports Das et al. slope toe erosion and is therefore assumed to be more favorable for landslides. 2022
Lineament proximity	Represents the rupture/shearing zones and their proximity adversely affects Martha proximity the stability by increasing the weak zones in the slope. et al. 2013.

Thrust-fault proximity	Landslide occurrences are inversely related to the thrust-fault proximities, as closer areas are tectonically unstable and often identified with fractured bed rocks.	Nath, et al. 2022
Road proximity	Hill slope modification through road cutting often reduces the slope stability specifically at weak rock mass zones and advances the landslide process.	Sarkar, et al., 2013
Lithology	It determines the thermal and geological characteristics of rocks. These properties significantly control the weathering resistance, which in turn affects the landslide process.	Samia, et al. 2018
Soil texture	Different hydrological conditions like soil transmissivity and hydraulic conductivity solely depend on the soil texture, and actively control the depth and type of landslides.	Das, et al. 2022

6.1.3 Moderate landslide Hazard Zone

This zone consists of the areas with vegetation that is neither too sparse nor too thick having the medium slope angles, and fairly dense sandstone rock formations. It is commonly considered as stable and considering as the current conditions remains undisturbed. While some of the sections in the study area having the steep slopes exceeding 45 degrees and the factors such as the orientation of rock layers, the absence of loose debris, and the minimal human intervention which can reduce the risk of hazards.

The Moderate Zone is widely scattered throughout the study area, including the several human settlements. However, seismic activity and prolonged heavy rainfall could weaken the slope stability. To minimize the risk in this zone, the natural drainage should remain undisturbed, and the slope modifications by human intervention should be avoided, whenever possible. Additionally, the future land use program must be carefully planned to preserve the zone's existing conditions. This zone covers an area of 110.70 sq. km, making up of the 16.24% of the total study area.

6.1.4 Low landslide Hazard Zone

This zone comprises an area of various slope stability factors which may cause for the minimal risk to slopes. The vegetation is moderately dense, and the inclination of slope is mostly low around 30 degrees more or less. A significant portion of this zone is placed over the hard and compact rock formations. The gently sloping with flatlands areas are also falls within this category. The human activities in this zone are either minimal or non-existent.

Since no signs of instability have been observed and the mass movements negligible, unless the major environmental changes occurred. This zone is well-suited for the infrastructure developmental projects. It spans an area of 3.32 sq. km, accounting for approximately 0.0048% of the total study area.

Table 6.2. The landslide hazard zonation types with the percentage of areal coverage.

Landslide Hazard zonation	Area in square	percentage
Low	3.32	0.0048
Moderate	110.70	16.24%
High	488.36	71.66%
Very High	79.10	11.66%
Total area	681.49	100

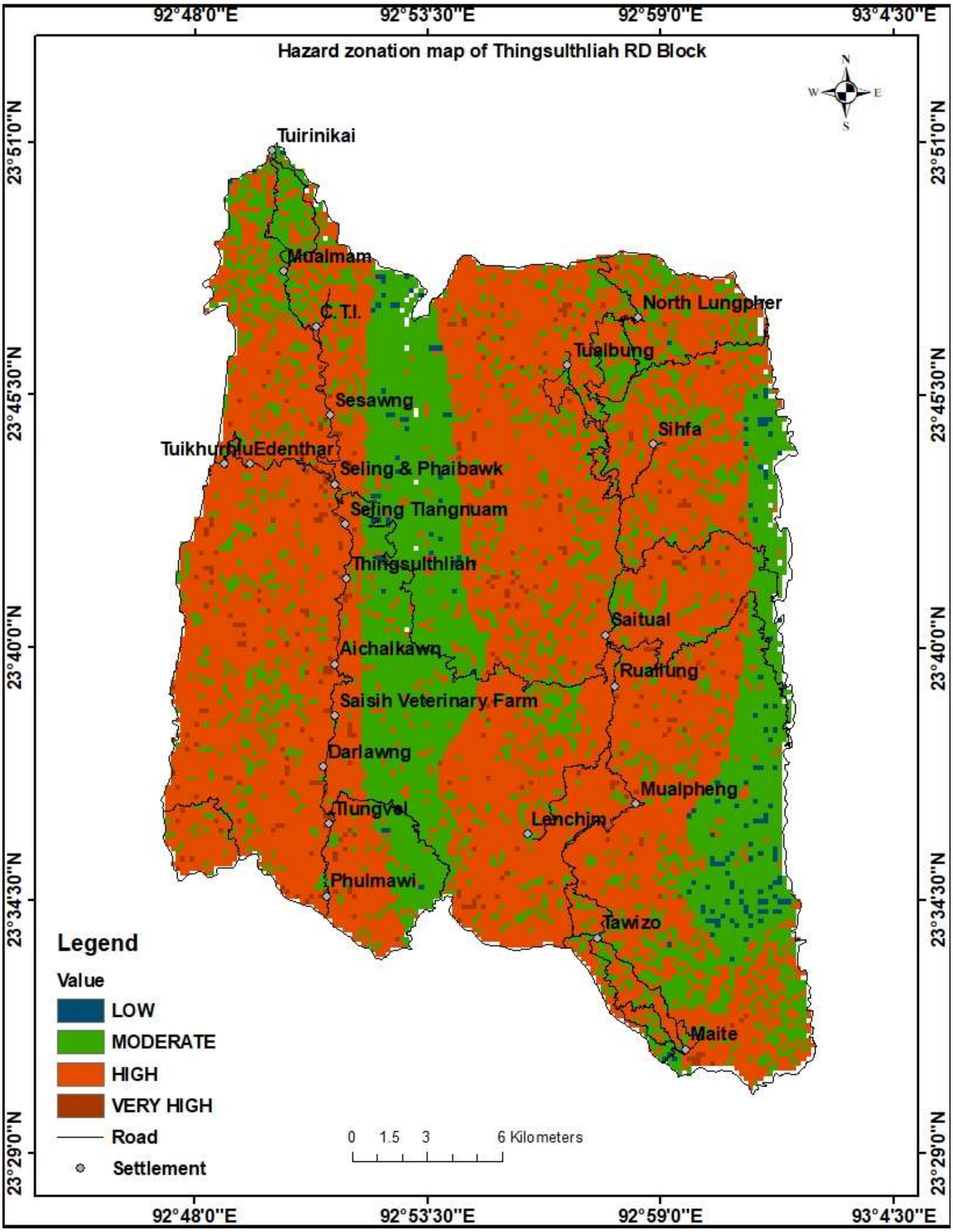

Figure 6.1. The distribution of the various landslide hazard zones in the study area.

6.2 Remedial measures

The benching is proposed for the areas with straight slopes, where the horizontal benches separate the slope segments. This technique enhances slope stability by breaking a long slope into smaller sections, allowing each segment to function independently. The appropriate bench width should be determined through slope stability analysis for the given soil conditions, but it should not be less than 4 meters. Benching also facilitates the settlement constructions, as it allows for the steeper slopes maintaining its stability.

Each bench should have a V-shaped or gutter profile with a proper drainage gradient, along with suitable catchment of the basins to channel the water down slope. To prevent erosion and water infiltration into permeable areas, ditches should be lined or paved.

In high and moderate hazard zones, forestation programs should be implemented. Additionally, the natural drainage systems should remain undisturbed, and slope modifications should be minimized. Future land use planning must be carefully managed to maintain the slope stability.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The study area is located in the central region of the Mizoram state, between 92° 47.090'E – 93° 02.55''E and 23° 30.40'N – 23° 50.75'N in the Aizawl district. It extends in the Survey of India toposheet Nos. 84A/13, 84A/14, 84E/1, and 84E/2 which is covering an area of 681.49 sq. km. The Tlangnuam and Aibawk RD blocks falls in the border region on the west, Darlawn borders it on the north, Champhai district borders it on the east, and Serchhip district borders it on the south.

Based on the study of the distribution generated various thematic layers facilitate the landslide hazard zonation in the Thingsulthliah Rural Development block. The high concentration of landslides along National Highway-52 suggests that natural slopes have been disturbed without adequate protective measures. In many areas, essential features like berms (raised barriers), surface and subsurface drainage systems, and stabilization techniques such as shotcrete (technique of prevent the slope/rock failure) or geo-grid planting for preventing the erosion. The combination of these factors, along with the low shear strength of excavated surfaces, saturated during the heavy rainfall has contributed to frequent landslides.

Geological factor such as rock formations are key contributors to landslide initiation, with the properties of rock units in hilly terrains largely determining slope stability. Due to their varying susceptibility to geomorphic processes, different rock types and structures make lithology plays a critical role in the landslide hazard zonation. The lithology influences slope stability by governing the shear strength and permeability characteristics of the materials involved. The lithological impact on the slope motions including rock falls, which are influenced by the weathering, fractures, and rock hardness, among other variables.

In the study area, a number of landslides have occurred due to monsoon rainfall conditions among the weak lithology, and the geological structures are the most important variables in determining the landslide risk. The Remote sensing data used for monitoring the temporal variations and quantify the geological features such as faults, fractures, etc. The geological rock formations in the hilly region controlled by the frequent slope failures are considered as susceptible landslide initiating sites because these fractures reduce the rock strength. Geological structures in the study area, including anticlines, synclines, and lineaments, have been identified by using the interpretation of remote sensing imagery. The occurrence of landslides is closely linked to both the geological formations and associated structural features. Discontinuities within the in-situ rock on hill slopes—such as joints, fractures, faults, bedding planes, and foliations—significantly affect the slope stability. These features often represent zones of weakness, increasing the vulnerability of slopes to landslides and other types of mass movement. The structural discontinuities, particularly when aligned with slope angles, have a greater impact on slope stability.

The study area consists of structurally controlled hill ranges having the highly dissected, undulating terrain with moderate slopes. Some of the hillocks exhibit sharp ridges and steep slopes due to intense erosion, while the others have gentle slopes and less dissection, suggesting that the landscape is in an early stage of the geomorphic development. The flat plains are scarce and mainly occur along stream courses and in between spurs. The study area is categorized into four major landform types such as moderately dissected structural hills, highly dissected structural hills, valley fills, and the low structural hills. The landslides tend to occur more frequently in the disturbed higher elevation zones than in the lower ones.

The study area displays varying degrees of relative relief, classified into high, medium, and local relief zones. The high relative relief typically corresponds to steep elevation changes and may be associated with fault zones, whereas low relief areas reflect a more mature and stable topography. Relative relief is a critical factor in landslide hazard mapping, as it significantly influences the risk to settlements, transportation routes, and land use patterns. The study area elevation ranges from 50 meters to a maximum of 1700 meters above mean sea level. It has been classified into three relative relief zones: high, moderate, and low. In general, areas at higher elevations are more prone to landslides compared to lower-lying regions.

A slope map of the study area was developed using STRM DEM data within a GIS environment to support the landslide hazard analyses. The slope map further classified as the slopes categories into seven classes based on the degree intervals such as 1. 0°-10°; 2. 10°-20°; 3. 20°-30°; 4. 30°-40°; 5. 40°-50°; 6. 50°-60°; 7. > 60°.

The aspect map of the study area was generated through satellite image interpretation. The slope aspect is a key factor for further landslide analyses, as it determines the slope orientation in relation to the sunlight exposure, wind patterns, rainwater accumulation, and the structural discontinuities in the rocks. The Hydro-meteorological factors such as solar radiation, precipitation, and terrain features—contribute to landslide initiation.

The Land use and Land cover (LULC) patterns are vital role for maintaining the slope stability. The vegetation, in particular plays a key role in preventing slope movements, especially in shallow slip or rupture zones. A strong root system increases the shear strength of the slope material by naturally stabilizing it. Furthermore, the vegetation helps in reducing the erosion and contributes to overall slope stability. In the study area, hill slopes are covered with overburden materials such as colluvium or a thin weathered layer. The dense vegetation or grass cover helps reduce physical weathering and erosion, thereby improving the slope stability. In contrast with the slopes having the poor or sparse vegetation cover are the areas more prone to weathering and erosion, increasing the risk of slope failure. When assessing the landslide susceptibility, land use and land cover (LULC) are critical factors to consider. The vegetation stabilizes the soil cover by strengthening it with its root system, significantly lowering the chances of slope failure.

Changes in water content of the soils leads to the density variations of the soils are the main cause for the landslides. These forces are greatly influenced by the characteristics of the soil, notably the amount of clays present. As a result, locations with clay-rich soils particularly those in hilly regions are more susceptible to landslides.

The saturated clays are the main source for the slope collapse and landslide occurrences in mountainous regions with the topographic variations. The clay loam and sandy loam are the two most common soil types in the area. Slope stability and landslip susceptibility are affected by the clayey soils that predominate at higher elevations and the sandy loam soils that predominate in low-lying locations.

Areas with a high drainage density typically have more frequent and stronger water flows, which can contribute to soil saturation, weakening the cohesion of soil or rock on a slope. This saturation can increase the risk of landslides.

The study finds the significant changes in the annual and seasonal rainfall patterns, as well as in the annual and seasonal rainfall anomalies in the study area. One of the main causes of the increasing frequency of landslides is changes in rainfall patterns on the vulnerable hill slopes.

Additionally, if a seismic event occurs, all the slopes in the region would be highly susceptible to failure. Therefore, a comprehensive inspection of slopes across the study area is necessary to assess the landslide risk. To mitigate the landslide risk, appropriate engineering measures should be implemented to enhance the slope stability and to minimize the future landslides.

The following conclusions and the suggestive preventive measures can be implemented to minimize the landslides in the Thingsulthliah Rural Development Block.

1. Identification of High-Risk Areas: The landslide hazard zonation has clearly identified and delineated the high-risk landslide prone areas within Thingsulthliah rural development block. These areas are characterized by the steep slopes, unstable soil conditions that increase the likelihood of landslides.

2. Vulnerable Settlements: The study highlighted the specific settlements within Thingsulthliah rural development block that are located in high-risk landslide zones. These settlements face a higher probability of landslide occurrences, posing significant risks to the residents and their properties. The necessary measures should be taken to assess the vulnerability of these settlements and implement appropriate mitigation strategies.

3. Slope Stability Analysis: The hazard zonation study involved a comprehensive slope stability analysis, which evaluated the stability of slopes throughout the area. This analysis helps in understanding the factors

contributing to slope failures and aids in the identification of critical areas that require immediate attention.

4. Land-Use Planning and Regulations: The landslide hazard zonation study provides the information for land-use planning and regulations in Thingsulthliah rural development block. The generated information can be useful for the rural development authorities for the appropriate action in the high-risk areas, such as restricting constructions or implementing necessary engineering measures to stabilize the slopes. The implementation of proper land-use planning can minimize the exposure of vulnerable populations and their infrastructure to minimize the effects of landslide hazards.

5. Mitigation Measures: The landslide hazard zonation study identified the constructive potential mitigation measures to reduce the landslide risk in Thingsulthliah rural development block. These measures may include the slope stabilization techniques, installation of retaining structures in the frequent slope failure areas, reforestation, and implementing the erosion control measures.

6. Early Warning Systems: The study emphasizes the importance of establishing early warning systems specifically tailored for landslides in Thingsulthliah rural development block. Early warning systems can promptly notify authorities and citizens, enabling evacuation and other necessary measures when required to minimize the impact of landslides.

7. Capacity Building and Awareness: The hazard zonation study highlights the significance of capacity building and raising awareness among the local population. The frequent training programs, workshops, and awareness campaigns can help the local community for understanding the landslides risk, familiar with the recognizing the warning signs, and adopt preventive measures to protect themselves and their properties.

8. Continued Monitoring and Evaluation: Landslide hazard zonation is a continuous procedure that necessitates continual assessment and monitoring temporally. The consistent temporal variations in slopes can cause for the

slope vulnerability, changes in land use, and the effectiveness of mitigation measures should be conducted to ensure the accuracy and relevance of the hazard zonation through time interval.

In conclusion, the landslide hazard zonation study provides the basic information for Thingsulthliah rural development to understand and manage the risks associated with landslides. By integrating the basic findings into the land-use planning, implementing mitigative measures, and enhancing community preparedness in the study area can minimize the potential impact of landslides and a safer living environment for its residents in the Thingsulthliah rural development block.

Landslide location 1. Landslide (Subsidence), Phulmawi.

Location 2. Landslide (Translational type), Phulmawi

Location 3. Landslide (Rockfall), Tlungvel-1,

Location 4.Landslide (Rockfall), Tlungvel Quarry.

Location 5. (Translational type) Tlungvel 3

Location 6. (Translational type), Rulchawm

Location 7.Landslide (Rockfall), Keifang Quarry.

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LISTS OF PUBLICATIONS

1.	Lalchhanhima, K. Srinivasa Rao, Laltlankima and Lalbiakmawia. Landslide Hazard Zonation along Sesawng Village and Seling Village Thingsulthliah Rural Development Block, Aizawl District.. Indian Journal of Natural Sciences. Vol.12 / Issue 65 / April / 2021 pp.29789-29805 ISSN: 0976 – 0997.
2.	Lalchhanhima, K. Srinivasa Rao, Laltlankima1 and Lalbiakmawia. Landslide hazard zonation along Phulmawi village and Tlungvel village road, Thingsulthliah Rural Development Block, Aizawl District, Mizoram, Eco. Env. & Cons. 28 (1) : 2022; pp. (244-249). ISSN 0971–765X.
3.	Lalchhanhima, K. Srinivasa Rao, C. Laldinglina, Laltlankima and Lalbiakmawia. Zonation of Landslide Susceptibility in Saitual Town Area, Mizoram. Indian Journal of Natural Sciences. Vol.12 / Issue 69 / December / 2021 pp.35297-35303 ISSN: 0976 – 0997.
4.	Lalchhanhima, K. Srinivasa Rao, C. Laldinglina, Laltlankima and Lalbiakmawia. Landslide Study at Tlungvel Quarry Areas, Aizawl District, Mizoram). Disaster & Development, Vol. 10, Issue 01, January to June 2021;pp.101-106. ISSN : 0973-6700

PRESENTATIONS

1.	Landslide hazard zonation along Phulmawi village and Tlungvel village road in Thingsulthliah Rural development Block,Aizawl District.3rd National Seminar on ‘ Natural Resourcces Management for sustainable Development(November7-8, 2019)
2.	Landslide hazard zonation along sesawng village and Seling village road in Thingsulthliah Rural development Block,Aizawl District Online international conference on ‘Recent Developments in Earth & Environmental Sciences, Natural Resource Management and Climate Change with special focus on Eastern Himalayas (October 8-9, 2020)

SEMINAR/ TRAINING etc ATTENDED

1.	Landslide mitigation & detailed project report preparetion. (NEHU & NDMA).
2.	Seminar’2020 Earthquakes in Mizoram’ (Directorate of Science & Technology)
3.	International Workshop on “Landslide Hazards in Mizoram”. (DGM, PUC&GSM)
4.	e-Training on “Revisiting Urban Risks:Planning for Complex Emergencies at 2:00 pm to 4:00 pm from 6-8 July 2020”(National Institute of Disaster Management(NIDM), Ministry of Home Affairs, New Delhi)

5.	e-Training on “Applications of Remote Sensing and GIS in Water Resources” (North Eastern Space Applications Centre, Umiam through online mode during 16th - 20th, November 2020)
6.	E-Training on “Satellite Photogrammetry and its Application”. ISRO (2020)
7.	e-Training on “Geospatial Inputs for Enabling Master Plan Formulation”. ISRO (2020)
8.	e-Training on “ Geospatial application for disaster risk management” ISRO (202)
9.	e-Training on “Climate Change, Landslides and SafeHill Area Development”, National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India in collaboration with Dr. RaghunandanSingh Tolia Uttarakhand Academy of Administration, Nainital, Uttarakhand.
10.	e-Training on “Art of Publication, Effective Writing and Presentation Skills in Earth Sciences” (RTD, NR, GSITI, Lucknow)
11.	e-Training on “Applications of Remote Sensing & Geographic Information System in Geosciences “organized at North Eastern Space Applications Centre, Umiam, Meghalaya.(2021)
12.	e-Training on “Engineering Geology and Landslide Studies”(RTD, SR, GSITI, Hyderabad)
13.	e-Training on “Basics of Structural Geology” ‘(T.C.Division of Geological Survey of India Training Institute, Hyderabad)
14.	e-Training on “Basics of Geographical Information System and its Applications”, (CGMT Division of GSI Training Institute, Hyderabad)
15.	e-Training on “Disaster Risk Reduction with Special Reference to Earthquake, Flood, Landslide, Fire and other Emergent Hazards”, (Department of Social Work, Rajiv Gandhi University, Arunachal Pradesh)
16.	e-Training on “ Cloud burst and flood”, National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India in collaboration with IMD, Govt of India.
17.	e-Training on “Refresher Course on Landslide Susceptibility Zonation and Site Specific Studies”, (RTD, NER, GSITI, Shillong)
16.	Virtual International Workshop “Unconventional Resources: Shale Gas & CBM Exploration & Exploitation”, Department of Petroleum Engineering and Earth Sciences, UPES, Dehradun & Department of Geosciences, University of Texas Permian Basin, USA.

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DATE OF PAYMENT OF ADMISSION	:	24.07.2018
APPROVAL OF RESEARCH PROPOSAL		
1 DRC	:	08.03.2019
2 BOS	:	05.04.2019
3 SCHOOL BOARD	:	26.04.2019
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ABSTRACT

LANDSLIDE HAZARD ZONATION OF THINGSULTHLIAH RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM, INDIA

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DEPARTMENT OF GEOLOGY

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

OCTOBER, 2025

LANDSLIDE HAZARD ZONATION OF THINGSULTHLIAH RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM, INDIA

BY

LALCHHANHIMA

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SUPERVISOR

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Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Geology of Mizoram University, Aizawl

Introduction

Mizoram's topography is geologically immature. There are steep-sloped anticlinal ridges that move north-south, with synclinal troughs in between. The steep fault scarps are a result of faulting in numerous places (GSI, 2011). As a result, landslides are common throughout the entire region. The tectonically active Himalayan regions are strongly linked to landslides, which are among the most frequent natural disasters that cause damage to residential areas and the transportation system in mountainous terrain (Gurugnanam, et al., 2012). Due to population density and development in both urban and rural areas, human settlements are becoming more and more susceptible to landslides. Therefore, when landslides happen in these types of human settlements, they can turn into a catastrophe (Chandel et al., 2011). Because of their high density and hillside positions, populations can be extremely vulnerable to natural calamities (Rawat et al., 2010).

Landslides are common in Mizoram due to its steep topography. Every year, a number of landslides are reported from a variety of locations and places. The most common reasons of slope failure in Mizoram are surface conditions rather than subsurface ones and/or seismic or volcanic activity, which occur rarely or never in the region. Since Mizoram is part of the Himalayan mobile belt, neo-tectonic activity and its associated components have played a significant role in causing slope collapse, particularly in geologically unstable locations such as proximity to active fault zones, unconformity, and so on

General Geology

Mizoram is a part of the Cenozoic-aged Tripura-Mizoram sedimentary basin (Evans, 1964). Here, the succession alternates between arenaceous and argillaceous. In terms of structure, the state has longitudinally plunging anticlines and synclines as well as N-S trending lines (Ganju, 1975, Nandy, 1982, and Ganguly, 1983). There are a few pockets of shell limestone, calcareous sandstone, and intra-formational conglomerates, but the main rock types exposed in the area are sandstone, siltstone, shale, mudstone, and their admixture in various proportions. The rock formations generally trend N-S with dips ranging from 20^{o} to 50^{o} either east or west

(Karunakaran, 1974). These are arranged in ascending order according to the Barail, Surma, and Tipam Groups. As determined by Karunakaran (1974) and Ganju (1975), the state's geologic sequence is listed in Table 2.1.It is debatable that the Barail succession exists in Mizoram. Barail succession has been demonstrated to exist in the eastern region ofthe State, near Champhai, by geologists from the Geological Survey of India, including Munshi (1964), Nandy (1972, 1982), and Nandy et al. (1983). However, geologists associated with the Oil and Natural Gas Corporation of India, including Ganju (1975), Ganguly (1975), Shrivastava et al. (1979), and Jokhan Ram and Venkataraman (1984), believe that the Barails are not found in Mizoram and that the rocks surrounding Champhai belong only to the Surma Group. DifferentLith units' spatial distributions show that the anticlinal cores of high amplitude folds are the only places where the Lower Bhuban succession is found. Usually found on fold limbs, the Middle Bhuban succession also occupies the centres of low amplitude anticlines.

While they are restricted to the synclinal cores in central and eastern Mizoram, the Upper Bhuban rocks form anticlines in western Mizoram. In the western and northwest regions of the State, Bokabil rocks are restricted to the cores of synclines in relation to Tipams(RamandVenkataraman,1984).

Objectives

The main objective of the study is to prepared Landslide Hazard Zonation map demarcating different hazard zone ranging from high to low zone in Thingsulthliah RD block area. Land slide hazard zonation mapping plays a vital role in road construction and planning of town, city and rural areas. The present study will provide landslide hazard area and which may act a tool for mitigating landslide in the study areas. The objectives of the study are as follow:

1. Thematic layers of lithological, structural, slope, slope aspect, Land use and land cover, relative relief, geomorphology will be prepared in GIS environment with a scale of 1:25000.

2. Preparation of Landslide Hazard Zonation map.

3. To suggest remedial measures to mitigate landslide in the study area.

1. Location of study area

The study area is located in the central region of the state, between 92° 47.090'E and 93° 02.55"E and 23° 30.40'N and 23° 50.75'N in the Aizawl district (Figure 1.3). It is included in Survey of India topographical maps No. 84A/13, 84A/14, 84E/1, and 84E/2. The Tlangnuam and Aibawk RD blocks border the region on the west, Darlawn borders it on the north, Champhai district borders it on the east, and Serchhip district borders it on the south.

2. Techniques and methods used:

Heuristic approach

The heuristic approach relies on the expertise of geomorphologists to assess landslide hazards. The key input of landslide hazard zonation is the landslide inventory map, followed by environmental factors, with experts assigning weighting values based on their judgment. This approach incorporates hierarchical levels and employs various methods for determining weighting factors. The hierarchical heuristic model is often integrated into a Decision Support System (DSS) to facilitate spatial decision-making (Castellanos and Van Westen, 2003).

Statistical approach

The statistical method to landslide susceptibility assessment aims to enhance objectivity in hazard evaluation (Van Westen, 1993). This method is particularly effective when past landslide events are critical for predicting future occurrences. The cornerstone of this approach is the landslide inventory map, which provides data on past events. By statistically analyzing the combinations of causal factors, this approach generates quantitative estimations of landslide probabilities for areas currently unaffected by landslides but sharing similar conditions (Soeters and Van Westen, 1996).

Physically-based modeling approach

Assessment of landslide hazard with the stability of slope model involves calculating safety factors to provide a quantitative stability index. Unlike other methods, this approach quantifies stability by evaluating safety factors. However, it has notable limitations. The complex calculation of safety factors, the need for extensive datasets, and the challenge of measuring the spatial distribution of parameters are significant obstacles (Van Westen, 1993). Experts have pointed out the additional drawbacks. Van Westen (1993) noted that due to insufficient input data—such as groundwater levels, soil profiles, and geotechnical characteristics—the method is only practical at small to medium scales. The safety factor values are not absolute; instead, they reflect varying conditions of slip surfaces and groundwater depth. According to Soeters and Van Westen (1996), this approach is suitable when the geomorphological and geology in the study area are relatively homogeneous, and the existing landslide types are simple.

This method utilizes the interpretation of field observations, remote sensing data, discussions with local people and past analyses of landslides within the study area (Soeters and Van Westen, 1996). It is considered approach to landslide hazard zonation as it identifies the spatial distribution and locations of different types of landslides.

Sl. No.	FACTOR	Rank in percentage	CLASS	WEIGHT-AGE
1	Slope (In degree)	25	0-10 10-20 20-30 30-40 40-50 50-60 >60	1 2 4 5 7 8 8
2	Soil	14	Clayey loam Sandy loam	8 4
3	Lithology	12	Shale-siltstone Sandstone-siltstone	8 4
4	Geomorphology	10	Highly Dissected Structural Hill Less Dissected Structural Hill Moderately Dissected Structural hill Inter-Montane Valley	7 4 3

			Fracture Valley	4 5
5	Rainfall	9	Low Moderate High	2 4 6
6	LULC	9	Dense Vegetation Moderate Vegetation Built up Scrubland Water Body	7 3 4 7 1
7	Drainage density	6	Perennial Non-Perennial	3 5
8	Lineament	6	Fault or Fracture	8
9	Relative relief (in meter)	5	50-600 600-1150 1150-1700	4 5 7
10	Aspect	4	Very low Low moderate High Very high	1 2 4 5 7

Table: The weightage factors assigned to the various generated thematic layers for the landslide hazard zonation in the study area.

Ten thematic maps were generated for weightage overlay technique by assigning weightage value. The following thematic maps were generated, they are as follow: -

i) Lithology
ii) Land use and land cover
iii) Slope morphometry
iv) Geological structures
v) Geomorphology
vi) Relative relief
vii) Slope aspect
viii) Soil
ix) Rainfall
x) Drainage density

Combining all the controlling parameters and by giving different weightage value for all the themes, the final LHZ map is prepared and categorized into 'Very High', 'High',' Moderate', 'Low' and 'Very Low' hazard zones. The output map is generated on a scale of 1: 25,000. Various hazard classes are described below:

i) Very High Hazard Zone

Geologically, this zone is highly unstable and is at constant threat from landslides, especially during and after an intense spell of rain. This is so, because, the area forms steep slopes with loose and unconsolidated materials, and include areas where evidence of active or past landslips was observed.

ii) High hazard zone

It mainly includes areas where the probability of sliding debris is at a high risk due to weathered rock and soil debris. It covers an area of steep slopes which when disturbed are prone to landslides. Most of the pre-existing landslides fall within this category.

iii) Moderate hazard zone

This zone comprises the areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. It is generally considered stable, as long as its present status is maintained.

iv) Low Hazard Zone

This zone includes areas where the combination of various controlling parameters is generally unlikely to adversely influence the slope stability. Vegetation is relatively dense, the slope angles are generally low, about 30 degrees or below.

v) Very Low Hazard Zone

This zone generally includes valley fill and other flatlands. Playgrounds are prominent features within this zone. As such, it is assumed to be free from present and future landslide hazard.