LANDSLIDE HAZARD ZONATION OF AIBAWK RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM

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

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LANDSLIDE HAZARD ZONATION OF AIBAWK RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM

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CERTIFICATE

This is to certify the thesis entittled, “ LANDSLIDE HAZARD ZOANTION OF AIBAWK RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM”, submitted by LALTLANKIMA for the award of the degree of DOCTOR OF PHILOSOPHY, is a research work, done under my supervision and guidance. The Thesis, submitted by him has not formed the basis of the award to the scholar for any other similar title and it has not yet been submitted as a dissertation or thesis in any university. I also certify that the thesis represent objective study and independent work of the scholar.

(Prof.K.SRINIVASA RAO)

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DECLARATION

Mizoram University

August, 2023

I **Laltlankima**, 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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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I - INTRODUCTION

1.1 INTRODUCTION

The topography of Mizoram is geologically immature. There is North-South trending anticlinal ridges with steep slopes with intervening synclinal valleys. Faulting in many areas has produced steep fault scarps (GSI, 2011). Therefore, the entire area is generally prone to landslide. Landslides are closely associated with the tectonically active Himalayan regions, and can be considered as the most common natural hazards which lead to damage in the road sector and residential areas in the hilly terrains (Gurugnanam, *et al*., 2012). The vulnerability of human settlements to landslides is continuously increasing due to concentration of population and developmental activities in urban and rural areas. Thus, landslide can become a disaster when they occur in such human habitations (Chandel, *et al*., 2011). Population can be highly vulnerable to natural disasters on account of high density and locations on hill slopes (Rawat, *et al*., 2010).

There are several records of severe landslide disaster within Aizawl district during the last two decades. In 1992, massive landslide in the stone-quarry at South Hlimen village claimed the lives of 66 inhabitants and 17 houses were destroyed by this incident. In 1994, areas of Aizawl Venglai locality, Ramthar locality and Armed veng locality were sinking which caused severe damage to 65 houses. In 1995, there was a long line crack at Hunthar locality alongside Aizawl to Sairang road (National Highway 54) and about 17 houses were dismantled. In 1999, the sinking area of Hunthar locality where the same incident occurred during 1995 sunk again endangering the structures of about 12 houses and 11 families within this area were evacuated. In 2008, one house was completely washed away by landslide at Saikhamakawn causing death of two persons and injuring four persons. During the monsoon of 2011, Lengpui Airport Road was blocked by landslide causing havoc to commuters and, within Aizawl city around ten houses were dismantled and about fifteen families were evacuated. In 2012, there was a long line crack at Ramhlun Sport Complex area around ten houses were dismantled and almost sixty families were shifted. In the same year, a massive landslide at a stone-quarry near Keifang locality (Saitual town) claimed the lives of eighteen people. During the month of

May 2013, there was a massive landslide at Laipuitlang locality within Aizawl city claiming the lives of seventeen persons. More than ten persons were injured, about twelve houses and sixteen vehicles were damaged. Due to the manifold miniseries and problems it causes to the public, several attempts were made to study landslide within the state of Mizoram.

A frequently used definition of landslide is “a movement of mass of rock, earth or debris down a slope” (Cruden, 1991). They can occur on many types of terrain given the right conditions of soil, rock, moisture condition and slope. Integral to the natural process of the earth’s surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides. Classification of landslides was first formally proposed by Varnes (1978) based on types of movement and types of material. A landslide can be classified and described by two nouns; the first describes the material and the second describes the movement. The material can be rock, debris and earth or a mix. The movement can befall, topple, slide, spread and flow. Hence, a landslide can be named as rock fall (‘rock’ is the material type + ‘fall’ is the movement type), debris flow and so on. It is recommended to use a combination of one/two of these nouns to describe a landslide, though in nature, we notice a mix of material sand movements and then we are tempted to use the term ‘complex landslide’, which normally should be avoided. The features and geometry of a landslide is explained in figure 1.1. Zonation refers to “the division of the land into homogenous areas or domains and their ranking according to degree of actual/potential hazard caused by mass movement” (Varnes, 1984). Landslide Hazard Zonation (LHZ) is defined as the “mapping of areas with an equal probability of occurrence of landslides of a given type and magnitude within a specified period of time” (Guzzetti, *et al.*, 1999; Varnes, 1984). Landslide hazard is commonly shown on maps as areas or zones, which display the spatial distribution of landslide hazard classes. To do this, the fundamental steps are the spatial prediction of susceptible zones, estimation on the probability of magnitude of future landslide and then temporal prediction of landslide recurrence in different susceptible zones. Landslide hazard estimates in turn, are the most crucial input to risk analysis, the latter being defined as “the expected number of lives lost, persons injured and damage to property and disruption of economic activity due to a particular landslide hazard phenomenon (Table 1.1) for a given area and reference period" (Varnes, 1984).

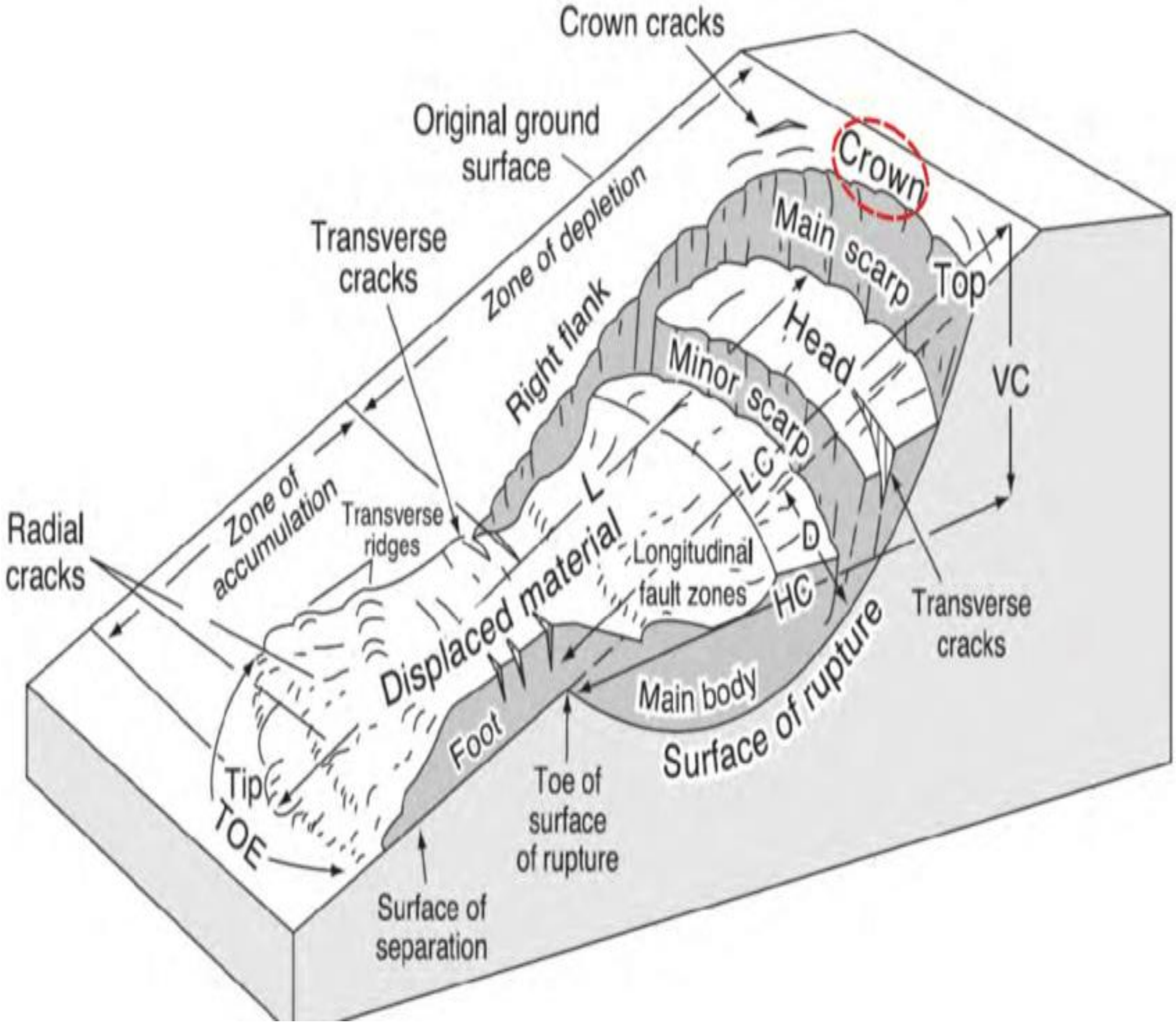


Figure 1.1: Block diagram of idealized complex earth of slide-earth flow (After Varnes, 1978).

Table 1.1: Abbreviated version of Varnes classification of slope movements (After Varnes, 1984).

Type of movement		**Type of materials**		
		Bed rock	**Engineering soil**	
			Predominantly coarse	**Predominantly fine**
Falls		**Rock fall**	**Debris fall**	**Earth fall**
Topples		**Rock topple**	**Debris topple**	**Earth topples**
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 two or more principal types of movement**			

1.2 Landslide's influencing factors

There are many factors that should be considered to analyze landslide hazard zonation (Varnes, 1984; Soeters and Westen, 1996) divided into 5 groups as described follow

- Geomorphology factors such as data of terrain unit, geomorphological sub unit, types of landslides.

- Topography factors such as data of digital terrain model, slope direction and length, concavities.
- Engineering geology factors such as data of lithology, material sequences, structure of geology, and seismic acceleration.
- Land use factors such as data of infrastructure (recent and older) and land use map (recent and older).
- Hydrology factors such as data of drainage, catchments area, rainfall, temperature, evaporation and water table map.

It may not be necessary to include all parameters because it depends which ones are relevant for the study area (Soeters and Westen, 1996). It also allows for the assessment of landslide vulnerability using only a few criteria. Cruden and Varnes (1996) separated landslide causal factors into two group; preparatory and triggering factors. They also divided landslide causes into geological, morphological, physical, and human-induced sources, as shown in the table 1.2.

1.3 General remarks

The State of Mizoram is located in the southeastern corner of the Northeastern India and is located between N 21 ° 58' - N 24 ° 35' Latitudes and E 92 °15' - E 93° 29' Longitudes. Tropic of Cancer passes through the middle of the State through Thenzawl Town. It is bordered by Myanmar to the east and south, Tripura state of India to the upper western half and Bangladesh to the lower western half, Cachar district of Assam to the north and Manipur to the north-east has an inter-state boundary of 123 km with Assam, 66 km with Tripura and 95 km with Manipur. Mizoram has a strategic location sharing an international boundary with two foreign countries, namely, Bangladesh (275 Kms) and Myanmar (475 Kms). The state covers a total geographical area of 21,087 sq. km. The entire state is a hilly terrain covered by hill ranges running mostly north - south direction parallel to each other and arranged in en-echelon manner. In between the hill ranges, one can see narrow valleys and deep gorges. The average height of the hills is about900 meter above sea level. The State comprises of 11 districts, namely, Lunglei (4,538 sq.km.), Aizawl (3,576.31 sq. km.), Champhai (3,185.83 sq. km.), Mamit (3,025.75 sq. km.), Lawngtlai (1,991 sq. km.), Saiha (1,965.81 sq. km.), Serchhip (1,421.60 sq. km.), Kolasib (1,382.52 sq. km.) and three newly created three districts viz Saitual, Khawzawl and Hnahthial districts respectively. Each district is under the charge of the Deputy Commissioner. For administrative purpose, the state is divided into 23 Sub-Divisions, 26 Rural Development Blocks and 3 Autonomous District Councils (Mizorarn Polution Control Board and Ministry of Environment and Forest, 2005).

Table 1.2: Contributory factor 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 discontinuit • 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

According to Census 2011, Mizoram has population of 10.97 Lakhs, an increase from figure of 8.89 Lakh in 2001 census. Total population of Mizoram as per 2011 census is 1,097,206 of which male and female are 555,339 and 541,867 respectively. In 2001, total population was 888,573 in which males were 459,109 while females were 429,464. The total population growth in this decade was 23.48 percent while in previous decade it was 29.18 percent. The population contribution of Mizoram forms 0.09 percent of India's in 2011. Out of the total population of Mizoram, 52.11% people live in urban regions. The total figure of population living in urban areas is 571,771 of which 286,204 are males and while remaining 285,567 are females. The urban population growth in the last decade has increased by 52.11 percent. The Sex ratio in urban regions of Mizoram is 998 females per 1000 males. Average literacy rate in Mizoram for urban region is 97.63 percent in which males were 97.98% while female literacy stood at 97.02%. The total literacy in urban population of Mizoram is 484,841.

1.4. Geomorphology

The state of Mizoram is rugged and hilly terrain with an aerial extent of 21,081 sq. km. The Mizo Hills (=Lushai Hills) is trending approximately north-south with a tendency to tapering in both the ends. The average elevation of the hills is about 900m and it increases towards the east. The highest peak is in the Blue Mountain (Phawngpui) along Myanmar border with an elevation of 2,065 m. The hills are generally steep and are separated by river valleys flowing either toward north or south direction forming deep gorges. The state of Mizoram topographic features in the state in Mizoram show prominent relief, as the terrain is immature nature due to recent tectonics. The major geomorphic features of the area are the structural hills and topographic ‘highs’ and ‘depressions’, flats nature in some of the hills and ‘slopes’ that are arranged in linear fashion. The physiographic expression in the state of Mizoram is characterized by approximately north-south trending steep slopes, mostly anticlinal in nature, longitudinal, and parallel to sub-parallel hill ranges and synclinal narrow valleys. The anticlines and synclines are intersected by transverse faults. The difference in elevation between valley floors and hilltops varies from west to east ranging from 200 m to 600 m (Karunakaran, 1974).

The area exhibits an angular, sub-parallel to parallel and dendritic drainage pattern. The lower order streams run parallel to the topographic ‘highs’ and ‘depressions.

1.5. Climate

The Mizoram state is receiving good amount of rainfall during monsoon season. The winter temperature varies between 11° to 21°C and in the summer temperature range is 20° to 30°C. The annual seasons is divided into four distinct parts namely spring (March-May), rainy season (June-August), autumn (September-November), and winter (December- February). During rainy season the climate in the lower hills and river gorges is highly humid in nature, whereas it is cool and pleasant in higher hills. A rather peculiar characteristic of the climate in this region is the occurrence of violent storms during the months of March-May. The strong storms arise from the north-west and sweep over the entire hills often causing extensive damage to dependent on horticulture crops. Heavy rains start in the month of June and continue up to the August. The September and October are the autumn months when the rains are intermittent and the temperature is usually in between 19^0C and 25^0C. Winter season receives very little or no rain.

The Aizawl city and its surrounding areas fall under the direct influence of the south-west monsoon. It rains heavily from May to September. September and October are the autumn months when the rains cease and the temperature is usually between 19°C and 25°C. As such the area receives an adequate amount of rainfall about 254cm annually, which is the main reason for a humid tropical climate which is characterized by the short winters and long summers. The southern part of Mizoram experiences more rainfall (350cm/year) as compared to northern part that receives about 208 cm of rainfall annually.

1.6 Drainage system

The drainage system plays a vital role in the generation of moisture content in the atmosphere as far as the growth of vegetation in an area is concerned. It is observed that most of the vegetation in the Mizoram occurs along the river courses and the adjoining areas. The drainage pattern of Mizoram is virtually shaped by its physiography and the geological structures. The drainage follows the synclinal valleys in between the parallel hill ranges. The drainage which runs through the depressions and gorges, forming angular dendritic drainage patterns. Most of the rivers either flows towards north or south in the state of Mizoram due to tactic in the form of tectonic Mat fault run north-west direction. The water holding capacity of the soil is low because of its clayey nature. The rainfall is the only source of water supply to the rivers of Mizoram. However, all the rivers are not perennial in nature.

There are number of rivers in Mizoram. The largest river is Tlawng (Dhaleshwari) which is 185.15 km in length. It is followed by Tiak (159.39 km in length), Chimtuipui or Kolodyne (130.46 km), Khawthlangtuipui or Karnaphuli (128.08 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), Tuivawl (72.45 km), Teirei (70.84 km), Tuirini (59. 57 km), Serlui (56.35 km) etc. The important rivers in the northern parts of the state are Tlawng-(Dhaleshwari), the Tuirial (Sonai) and the Tuivawl. The river Tlawng (Dhaleswari) passes from South to North in the western parts of Mizoram and then it enters into Cachar plain and ultimately joins Barak River. Originating from Zowbawk village (8 km East of Lunglei town) and engulfing the tributaries, viz. Gutur (Tut) and Pakwa (Teirei) in the western flank, and medium Lui and Bhairabi Cherra from the eastern side it flows majestically in North. Tut and Teirie run parallel to Tlawng for about 60 km and then join the Tlawng. Similarly, other North flowing rivers, like Sailut Lui and Langkaih (Longai) and Thingtlang (Singla) are important. The river Longai forms the border between Tripura and Mizoram in the West.The river Tuivawl and its tributary Tuival forms an important drainage system in the North-east part of Mizoram. These rivers form the borderline between Mizoram and Manipur and finally join Barak River of Tipaimukh.

In the southern part of Mizoram, the Chimtuipui drainage system is important where river Chimtuipui (Kolodyne) has four tributaries - the Mat, the Tuichang, the Tyao and the Tuipui. It forms boundary line between_India and Myanmar in the South eastern part of Mizoram. It originates from the mountains in Myanmar, flows first westward and then southwards in Mizoram and then reenters the Myanmar.

The Khawtlangtuipui (Kamafuli), with its tributaries - the Tuichawng, the Phaireng, the Kun, the Deh and the Tuiliangpni form the western drainage system. This river originates from central hills of Mizoram and flows westwards into Bangldesh at Demagiri and finally joins Bay of Bengal. The drainage system is of rectangular or parallel pattern. The river Tuichang and its tributaries Matlui, Jamilalui and Tlangpuilui join from the South - west and Damtelui, Rangtalui, Roilui from the East. Similarly, the Tuivawl, the Tuichang and Tuilianpui have parallel courses for quite a length, but run in opposite directions. The Tuichawng and the Phaireng flow northward and join the Deh.

1.7 Soil types

Soil type of Mizoram varies from sandy loam to clay, generally mature but leached due to steep gradient and heavy rainfall. Soils are porous with poor water holding capacity and are deficient in potash, phosphorus, nitrogen and exhibit acidic to neutral pH. Soils of Mizoram are primarily derived from secondary rocks of the Barail, Surma and Tipam series of the Miocene to Pleistocene period. Quality of the soils is mainly influenced by the topography and climate of the region. As such the various microclimatic conditions in complex physiographic structure are primarily responsible for the development of the soil in the state. The lower slopes of the hills and valleys are bestowed with rich fertile soils as opposed to steep sides of barren rocks of high mountains. The soils on the top of ridges are mostly shallow or underlain by weathered rock and have thin depth. They have poor moisture supply and are capable of supporting only scrubs and low tress. In narrow valleys, the extent is very much limited and is of least important for land use. The soil in flat lands is poorly drained. However, in general the soils of Mizoram are well drained except in few flat lands, and are capable of providing substantial oxygen supply for plants growth. Mostly soils have capability to retain soil moisture and maintain its supply throughout the growing season of normal crops. They have low inherent fertility in the form of poor supply of mineral reserves.

Soil types of Mizoram are broadly classified into alluvium and residual soils. Alluvium soils are found at the foothills of the northern and western plains and valleys. The soils are young and dominated by coarse sand. Residual soils are further classified as lateritic brown earth and podzolic and occur on steep slopes in most part of the state. The texture of the soils varies from sandy loam and clayey loam to clay. They are generally mature but heavily leached owing to heavy rainfall and steep gradient. Mizoram soils are porous with poor water holding capacity. The soils in the valleys are heavier as the rain water brought them down from high altitudes.

The pH of the soils is in the acidic range but sometimes approaches neutral due excessive leaching. The soils of the State are fertile and responsive to fertilizers. The soils of Mizoram are dominated mainly by loose sedimentary formations. Derived soils with red, loamy texture are also found with high levels of laterite. They are rich in organic carbon but deficient in potassium and phosphorus, nitrogen and humus content. But in an eroded soil, the content of nitrogen is quite high, enriched by the accumulation of organic matters. The soils of the different physiographic units of Mizoram are homogenous in nature but as far as the genetic aspect of the soil formation is concerned, they are mainly derived from sandstones, shales and siltstones.

1.8 Flora and Fauna

Mizoram has vast natural resources including forests and wildlife. According to India State of Forest Report (ISFR, 2015), an area of 18,748 sq. km which is 88.93% of the total geographical area (21,087 sq. km.) of the State is under forest cover in Mizoram. Of this, about 138 sq. km. is Very Dense Forest (VDF), 5,858 sq. km. Moderately Dense Forest (MDF) and 12,752 sq. km. of Open Forest (OF). Besides, about 535 sq. km. of the area is under tree cover. Thus, total forest and tree cover area of State account for 19,283 sq. km. which is about 91.42% of the total geographical area of the State.

Mizoram has abundant resources of flora and fauna which is distributed among blossoming green, diversified topography with steep slopes separated by rivers gently sloping towards north and south. The state has a variety of Timber species and Bamboos also occur abundantly present in throughout the state. Mammal species found in Mizoram forests are Slow Loris, the state animal Red Serow, Goral, Tiger, Leopard, Clouded Leopard, Leopard Cat, and Asiatic black bear, Sun bear. Many reptiles, amphibians, fish and invertebrates are found in Mizoram. The state is a habitat for 8 species of primates and a large number of invertebrate faunas also inhabit the State (Mizoram Forest report, 2016).

1.9 Rainfall

The weather of the state is highly affected due to any cyclonic development in the Bay of Bengal because of its short aerial distance from the ocean system. The state receives quite a sizable amount of rainfall not only during the monsoon season, but also as and when any cyclonic system hits the area. The climate of Mizoram is neither very hot nor very cold, but moderate throughout the year. The whole state falls under the direct influence of south-west monsoon and receives an adequate amount of rainfall. The climate of the state is humid-tropical, characterized by short winter, long summer with heavy rainfall. The fluctuation in temperature is not much and the highest temperature is observed during May to July and starts decreasing with the onset of monsoon. The study area has highest rainfall in 2006 (3375.4 mm) and the lowest rainfall in 2010 (2047.4 mm) during 1986-2015 as reported by State Metrological Center (SMC, 2016). Landslides triggered by monsoon rainfall are a recurring hazard that lead to loss of life and cause enormous property and infrastructure damage in the Mizoram. The annual rainfall recorded during 1986-2015 is shown in table 1.3.

Table 1.3: Average monthly rainfall 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

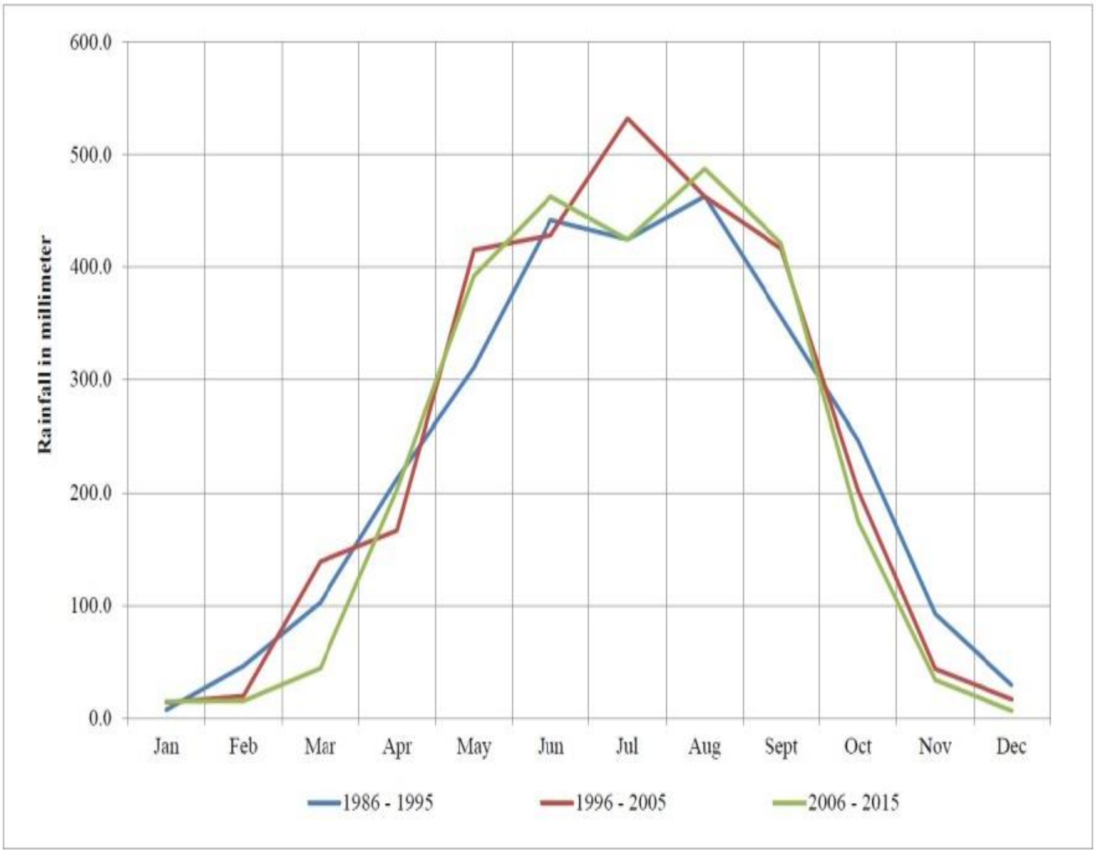


Figure 1.2: Decadal changes of rainfall (mm) in Aizawl district (1986-2015).

1.10 General Geology

Mizoram, geologically, is a part of the Tripura - Mizoram sedimentary basin of Cenozoic age (Evans, 1964). Argillaceous and arenaceous succession occurs here in alternation. Structurally, N-S trending and longitudinally plunging anticlines and synclines occur in the state (Ganju, 1975, Nandy, 1982 and Ganguly, 1983). The rock formations trend generally N-S with dips varying from 20º to 50º either towards east or west (Karunakaran, 1974). Main rock types exposed in the area are sandstone, siltstone, shale, mudstone and their admixture in various proportions and a few pockets of shell limestone, calcareous sandstone and intra-formational conglomerates. Sequentially, these are grouped into the Barail, the Surma and the Tipam Groups in the ascending order. The stratigraphic succession in the state as worked out by Karunakaran (1974) and Ganju (1975) is given in Table 4.1.

Presence of the Barail succession in Mizoram is rather controversial. Geologists of the Geological Survey of India like Nandy (1972, 1982) and Nandy *et al.* (1983) have shown the occurrence of Barail succession in the eastern part of the State around Champhai. Geologists of the Oil and Natural Gas Corporation of India, namely, Ganju (1975), Ganguly (1975), Shrivastava *et al.* (1979), Jokhan Ram and Venkataraman (1984), on the other hand, are of the opinion that the Barails do not occur in Mizoram and the rocks around Champhai should be included in the Surma Group only.

The spatial distributions of various litho-units indicate that Lower Bhuban succession is exclusively confined to the anticlinal cores of high amplitude folds. The Middle Bhuban succession is generally exposed on limbs of folds and they also occupy the cores of low amplitude anticlines. The Upper Bhuban rocks form anticlines in western Mizoram but are confined to the synclinal cores in central and eastern Mizoram. Bokabil rocks *vis-à-vis* Tipams are limited within the cores of synclines in the western and northwestern parts of the State (Ram and Venkataraman, 1984).

Structurally, the Mizo Hills are considered to be forming an integral part of the mobile belt constituted of very tight, sub-parallel, elongated, doubling plunging folds. The folds are sub-meridionally trending anticlines alternating or en-echelon with broad saucer shaped synclines. The fold belt is slightly arcuate in shape with westward convexity (Srivastava, *et al*., 1979). The intensity of deformation becomes progressively lesser when moving from east to west across the fold belt and the succession also becomes younger in the same direction. Thus, the western flanks of the State along with the neighboring areas i.e., Tripura and Cachar district of Assam are typified by younger rock formations folded into narrow, box-like anticlines in alternation with wide and flat synclines, while the eastern part of the state is characterized by relatively older rock formations folded into tight, linear anticlines and synclines (Ganguly, 1983).

1.11 Objectives

The main objective of the study is to prepared Landslide Hazard Zonation map demarcating different hazard zones ranging from high to low zone in Aibawk Rural development block area. Land slide hazard zonation mapping play a vital role in development of infrastructures and town planning. The present study provides the landslide hazard zonation information, which will be helpful for the planner to sustainable development of the area. The objectives of the study are as follow:

1. To generate thematic layers of lithological, structural, slope aspect, Land use and land cover, relative relief, geomorphology by using in GIS environment with a scale of 1:25000.
2. To prepare Landslide Hazard Zonation map.
3. To suggest remedial measures to mitigate landslide in the study area.

1.12 Location of study area

The study area lies in the central part of the state between 92^{o} 38.140’E to 92^{o} 50.738” E and 23^{o} 18.460’N to 23^{o} 39.586’N in Aizawl district (Fig. 1.3) and falls under Survey of India topographical map No. 84A/10, 84A/11, 84A/14 and 84A/15.

The area is bounded in the west by Reiek and Bunghmun Rural Development blocks (Fig. 1.4), in the north by Tlangnuam and Thingsul RD blocks and the eastern and southern side by Serchhip RD block. The entire Rural Development blocks in the state of Mizoram having 26 administrative divisions in the state of Mizoram are mentioned below:

1. Aizawl district: 1) Tlangnuam R.D. Block 2) Darlawn R.D. Block
3) Phullen R.D. Block 4) Aibawk R.D. Block
5) Thingsulthliah R.D. Block

2. Lunglei District: 6) Lunglei R.D. Block 7) Lungsen R.D. Block
8) Hnahthial R.D. Block 9) Bunghmun R.D. Block

3. Saiha District: 10) Saiha R.D. Block 11) Tuipang R.D. Block

4. Kolasib District: 12) Thingdawl R.D. Block 13) Bilkhawthlir R.D. Block

5. Mamit District: 14) Zawlnuam R.D. Block
15) West.Phaileng R.D. Block
16) Reiek R.D. Block

6. Champhai District: 17) Champhai R.D. Block 18) Khawzawl R.D. Block
19) Ngopa R.D. Block 20) Khawbung R.D. Block

7. Serchhip District: 21) Serchhip R.D. Block 22) E.Lungdar R.D. Block

8. Lawngtlai District: 23) Lawngtlai R.D. Block 24) Bungtlang ‘South’
25) Chawngte R.D. Block 26) Sangau R.D. Block

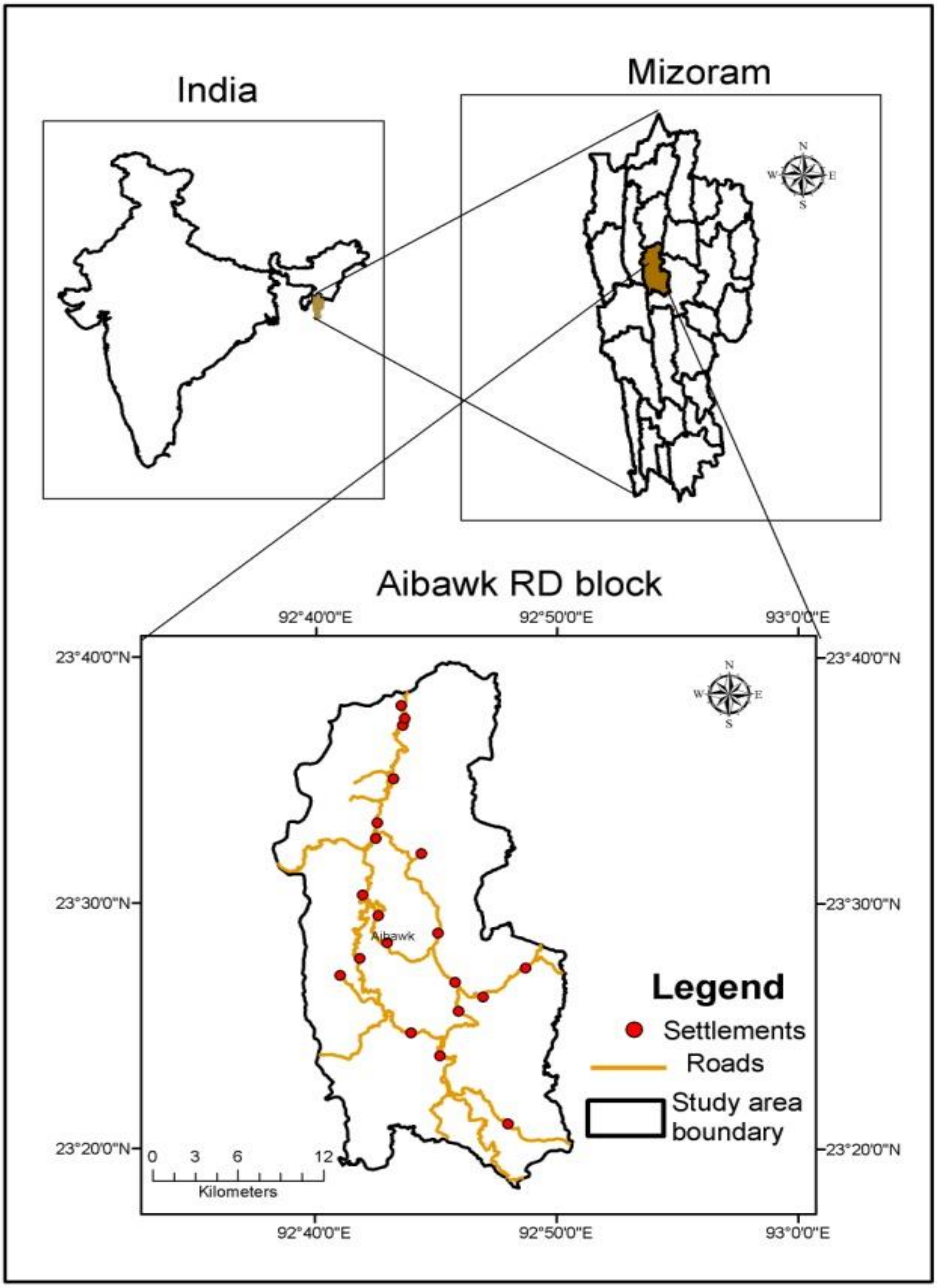
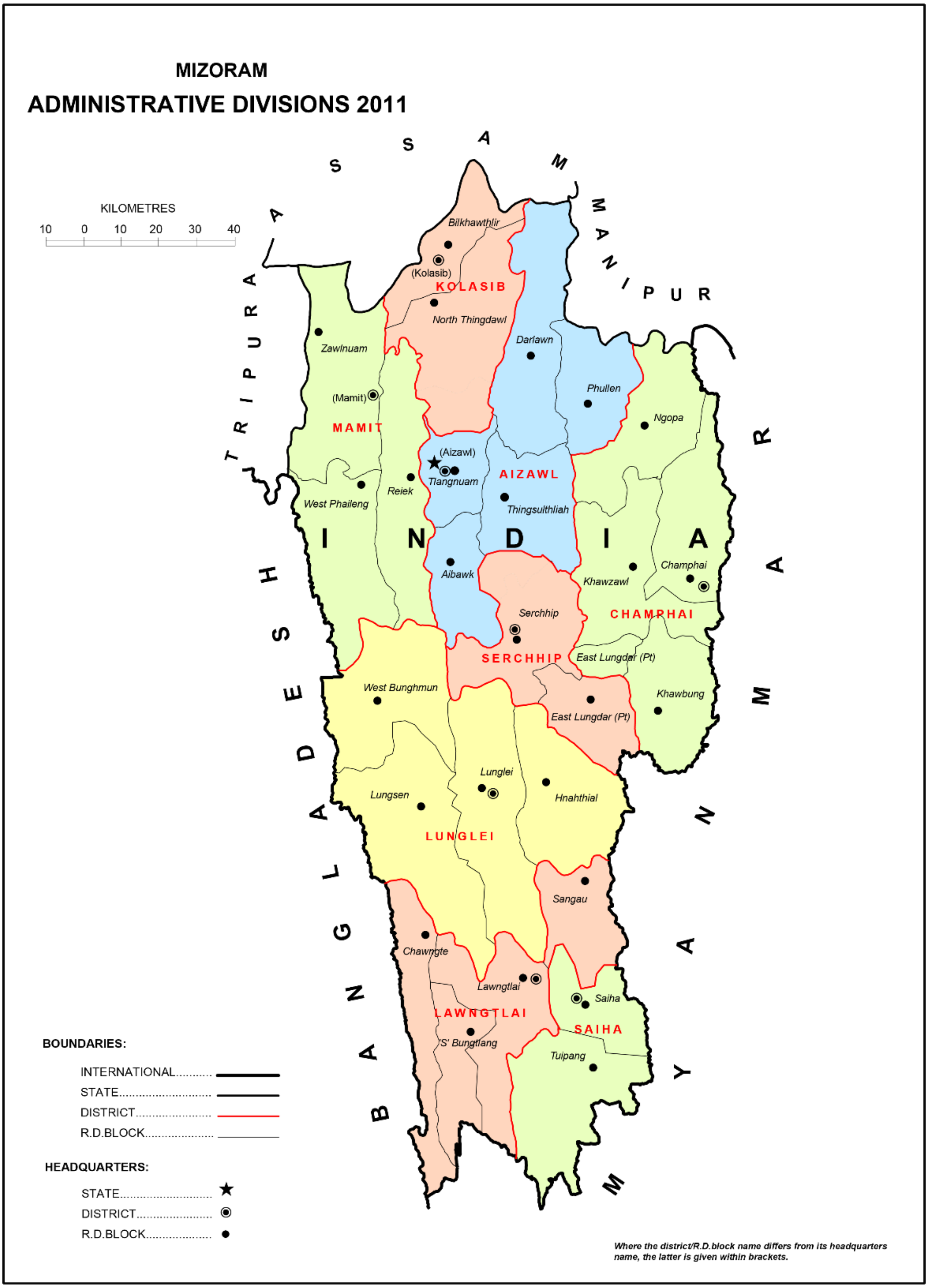


Figure 1.3: Location map of the study area.



Where the district/R.D.block name differs from its headquarters name, the latter is given within brackets.

Figure 1.4: Administrative rural development blocks of Mizoram state.

The Aibawk rural development block area statistics is shown in detail in the given table 1.4.

Table 1.4: Aibawk Rural Development block statistics of 2014.

Sl. No.	**Name of villages**	**No of households**	**Population as per 2011 census**		
			Male	**Female**	**Total**
1	Hualngohmun	187	430	421	1041
2	Melriat	271	578	543	1397
3	Kelsih	154	234	271	663
4	Falkawn	276	911	889	2081
5	Muallungthu	265	820	758	1848
6	Tachhip	193	525	505	1228
7	Aibawk	338	682	694	1719
8	Sateek	224	430	419	1078
9	Phulpui	198	579	548	1329
10	Maubuang	96	331	310	471
11	Thiak	156	402	421	983
12	Sumsuih	180	428	401	1013
13	Hmuifang	62	190	120	375
14	Lamchip	161	511	467	1142
15	Chawilung	105	290	230	628
16	Chamring	56	167	157	383
17	Lungsei	53	141	125	322
18	Samlukhai	227	852	882	1964
19	Sialsuk	456	1087	1081	2627
20	Sailam	135	431	439	1008
Total	--	3793	10019	9681	23570

Table 1.5. Aibawk Rural Development block statistics (2001)

Sl No	**Name of villages**	**No of households**	**Population as per 2001 census**		
			Male	**Female**	**Total**
1	Hualngohmun	130	293	316	609
2	Melriat	161	489	349	838
3	Kelsih	129	314	365	679
4	Falkawn	165	422	437	859
5	Muallungthu	196	487	509	996
6	Tachhip	167	421	472	893
7	Aibawk	294	653	665	1318
8	Sateek	167	405	450	855
9	Phulpui	165	486	498	984
10	Maubuang	74	232	215	447
11	Thiak	124	354	367	721
12	Sumsuih	142	384	382	766
13	Hmuifang	37	96	104	200
14	Lamchip	121	331	352	683
15	Chawilung	94	240	213	453
16	Chamring	38	109	118	227
17	Lungsei	31	112	121	233
18	Samlukhai	197	609	645	1254
19	Sialsuk	379	1087	1081	2095
20	Sailam	113	431	439	744
Total		2924	7955	8098	15854

According to Census record the population of Aibawk rural development block increases from 15854 to 23570. The number of household increase from 2924 to 3793. The number of household number may be increases continuously after the functioning of Zoram Medical College as the main medical center in Mizoram.

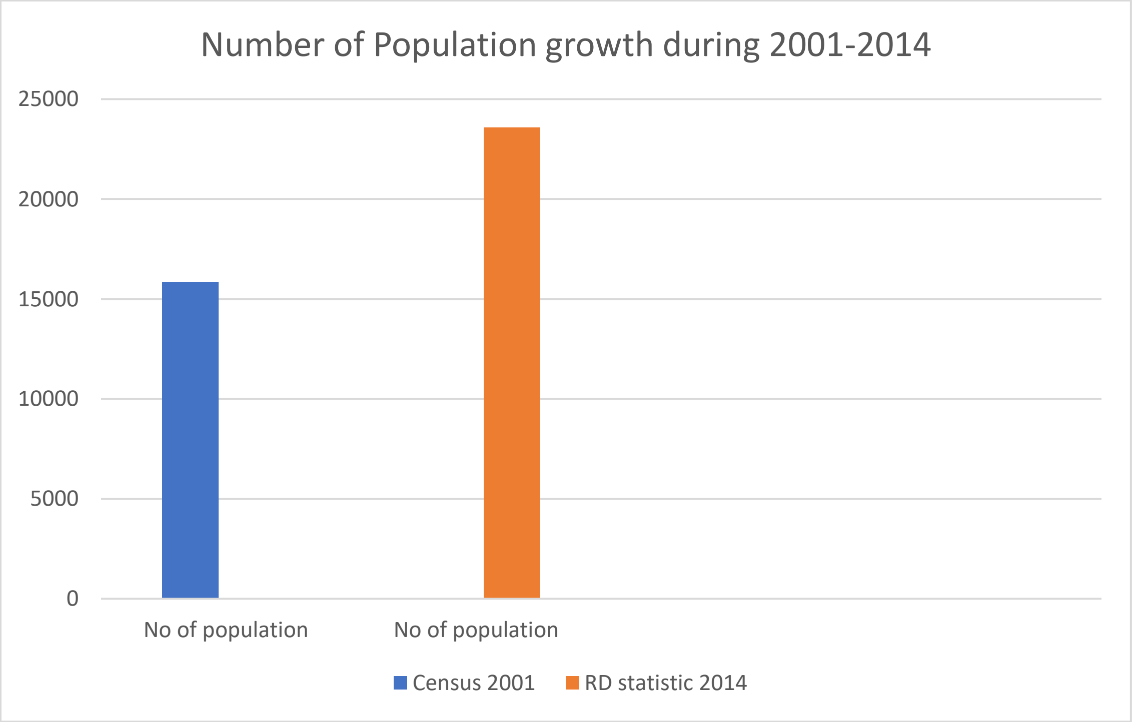


Figure 1.5: Census 2001 and Rd statistical handbook,2014

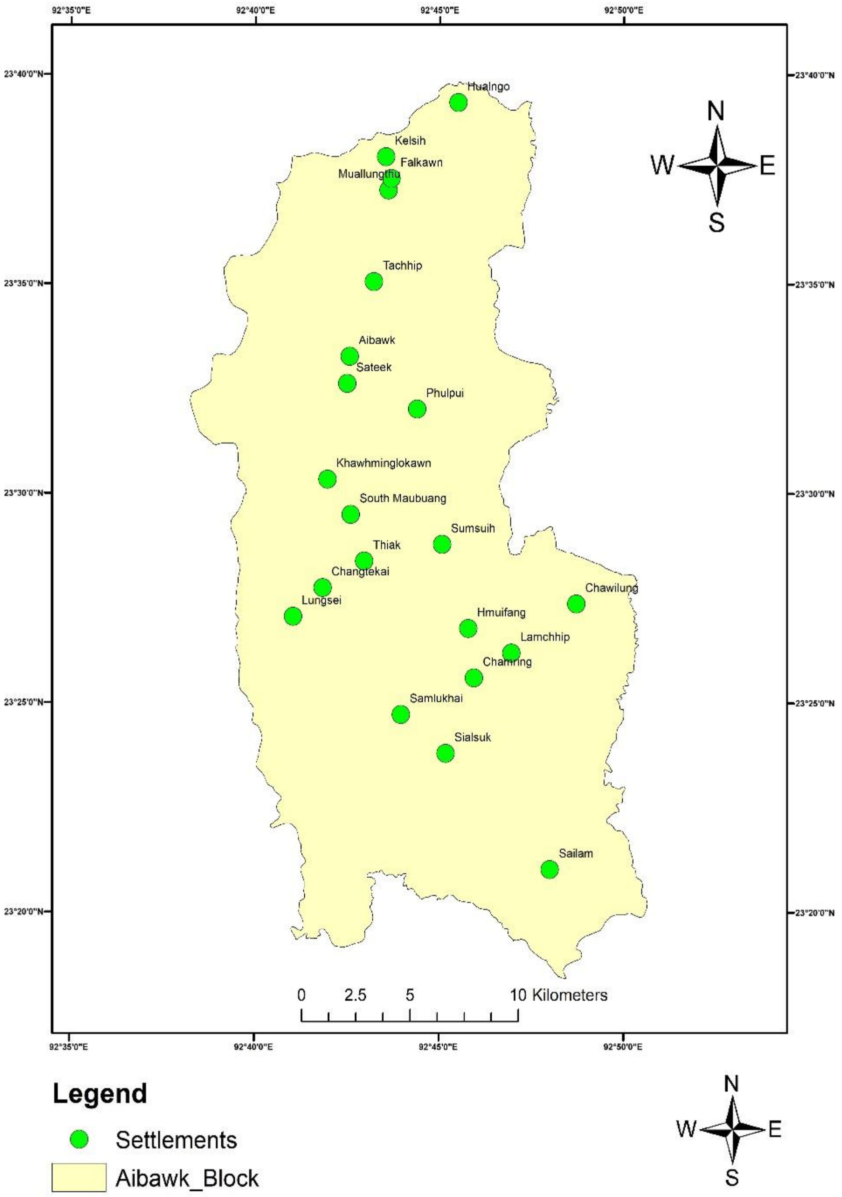


Figure 1.6: Settlement map of Aibawk Rural development Block

CHAPTER II - REVIEW LITERATURE

REVIEW LITERATURE

A broad variety of journals which are published by International, national and state level are reviewed. Different author used different method and techniques to achieved and generated hazard zonation map in their work. Their approach and methodology are quite different from each other and there is no specific method for generating landslide hazard zonation map. It depends on the research approached and selected method to achieve their objective.

Ayele et al. (2014) stated that Weighted overlay method is a simple and direct method that can be used for the evaluation of landslide hazard in the given area.

Castellanos Abella and Van Westen (2008), made Landslide vulnerability assessment model by multi criteria analysis utilizing a subjective methodology where they consolidated all weight into hazard value for each pixel count for landslide susceptibility map, in view of their investigation, decisions with respect to the different conditions under which slope failure occur.

Choubey and Lallenmawia (1987) have done landslide study on selected landslide areas in Aizawl city. The noticed that tectonic movement of the region, different setting of geology and structure play a vital role in the causes of landslide in their study areas

Choubey (1992) studied landslide in Vaivakawn area with geotechnical technique in laboratory to simulate sliding movement and make corrective measure for landslide affected area.

Dahal et al. (2008) studied that Geographic Information Systems (GIS) with capability of handling and integrating multiple intrinsic variables in relation to the spatial distribution of landslides has gained the success in landslide hazard mapping.

Dai and Lee (2002) stated that landslide inventory mapping is considered to be straight forward and is required for most of the susceptibility and hazard zonation techniques.

Guzetti et al. (1999), stated that the limits involving the methodologies are not inflexible, particularly in the heuristic methodology, which is the not direct mapping method consisting of mapping a huge quantity of controlling factors considered to possibly influence landslides in an area and ultimately examined all these causative factors with respect to slope instability.

Guzzetti et al. (2003) discussed three landslide event inventories and compared them using universal frequency-area statistics. They discussed the significance of completeness and resolution of landslide inventory maps in the landslide investigations. The results of the study portray that number of landslide events rapidly increased with increasing landslide area up to a maximum value and decreased as power law function.

Guzzetti et al. (2007) the consistent with research showing that physically based models experimenting with various rainfall thresholds forecast shallow landslides quite well, but they become less accurate when predicting deep-seated landslides.

Jones et al. (2021) Mass-wasting is significantly higher during monsoon seasons that include intense rainfall events than it would be predicted from overall monsoon rainfall levels. To assess the relative relevance of severe rainfall bursts and continuous monsoon rainfall in terms of landslide erosion and danger more effectively if we establish individual landslide timing.

Lalbiakmawia and Lallianthanga (2014) prepared landslide susceptibility zonation of Kolasib district, Mizoram and they categorized landslide hazard zone into very high hazard, high hazard, moderate hazard, low hazard and very low hazard. They generated landslide susceptibility map with a scale of 1 :50000.

Kanungo et al. (2006) stated that the numeric numbers assigned to factor class are termed as ratings and the numbers assigned to respective causative factors are known as weight.

Lahai et al. (2021) mentioned the human interventions such as the construction of highways, human settlements, and plantations in place of natural vegetation dominate the modern environment. These actions made it easier for an unexpected, heavy rainfall storm to cause landslides.

Lallianthanga and Laltanpuia (2013) carried out study of landslide in Lunglei town using high resolution satellite data and Geographic information system. They applied Heuristic methodology for assignment of ranks and weight with prior knowledge of the experts. The categorized hazard zonation into five zones which ranges from low to very high hazard zones.

Lalbiakmawia and Laltlankima (2016) prepared Landslide Hazard Zonation Map along Aizawl city and Lengpui airport road and they categorized hazard zones into six zones and they also made suggestion for remedial measures.

Lalrokima et.al (2016) have carried out Landslide hazard zonation of Saiha District, Mizoram, India using Remote Sensing and GIS based on the integration of data acquired from various geological and environmental thematic databases and assigning weightage values for each theme and concluded that very high hazard zones occupies a total of 9.89% of the area, High Hazard zone occupies 24.35% of the total area whereas Moderate Hazard area occupies about 42.72%, Low hazard zone and Very low Hazard zone constitutes 19.96% and 2.22% respectively.

Laltlankima et al (2020) carried out Landslide hazard zonation along national highway within Aibawk block and prepared landslide hazard zonation map which was categorized into five classes. Each thematic layer was assigned to different ranking and weightage values.

Martha et al. (2013) applied this method to assess spatial landslide probability in Rudraprayag district of Garhwal Himalaya, India using semi-automatically created landslide inventories.

Mazumdar (1980) arranged the first landslide hazard zonation map of the whole North-East India on the 1:100,000 scale. He further ordered the landslide hazard zonation map into six zones. He contemplated and arranged the landslide hazard zonation map in relation to the geology, geomorphology and hydrology of the area. In this landslide hazard zonation map, Mizoram falls in the moderate/modestly high-risk zone.

Kartic Kumar et al (2013) carried out landslide susceptibility mapping in Kothagiri Region, Western Ghats, Tamil Nadu, India and the landslide susceptibility map was prepared using rating values and is reclassified into four classes showing low to very high susceptibility classes. The analysis of the susceptibility modeling results shows the high significance of slope, drainage density, geological and land cover parameters. The landslide susceptibility map can be used to reduce damage associated with landslides and to land cover planning.

Panikkar and Subramaniyan (1997) carried out landslide hazard assessment using GIS based weighted overlay method in the area around Dehradun and Massori of Uttar Pradesh, currently Uttarakhand in India. The study revealed that rapid deforestation and urbanization have triggered landslides in the study area.

Raghuvanshi et al (2014a, 2014b) stated that the landslide susceptibility and hazard evaluated by heuristic technique for a given area may vary considerably if evaluated by different experts. However, these techniques are popular because of their simplicity in application. These techniques are based on data, primarily acquired from the field and are well supported by the judgment and experience of an evaluator.

Shahabi and Hashim (2015) identified precipitation as the primary factor associated with landslide sensitivity in the tropical climatic zone.

Sidle and Ochiai (2006) assessed that the effects of climate change on landslides have been studied through in their assessment of the factors and mechanisms influencing landslide phenomena. They came to the conclusion that the two most significant climate variations that may have an impact on landslides were changes in regional annual and seasonal precipitation and an increase in mean air temperature. They noted that the associated feedback processes added more complex interactions to an already challenging evaluation, but they nonetheless took into account the effects of climate change on flora, soil, land use, and land cover.

Tempa et al. (2021a, b) stated extreme weather events have led to major disasters in the form of storms, floods, and landslides, which have caused enormous socio-economic damage.

Gupta and Joshi (1990) worked on Landslide Hazard Zoning utilizing GIS based method from the Ramganga catchment, Himalayas. They acknowledged that separately from the factors like land use, tectonic features and local features like places of sharp river bends, areas under-cut by streams and toe-cuttings, seismicity and precipitation are the other two significant factors which have key bearing on landslide activity in this area.

Gupta et al., (1993) arranged Landslide hazard Zonation map of the upper Salluj valley, Kinnaur district, Himachal Pradesh. They established that 13 percent of the total all the region fall exceptionally in very high hazard zone, 10 per cent in high hazard zone, 34 per cent in moderately hazard, 34 per cent in low hazard and only 9 per cent in very low hazard zone.

Laldinpuia et al. (2011) has studied Ramhlun Vengthar landslide, Aizawl with geotechnical methodology. They found out that steepness of the slope, improper drainage system, high precipitation of rain and erosion on the toe led to landslide in the study area. Reduction in shearing strength is due to such factors which led to landslide, this causes of loss houses in the area.

Laldinpuia et al. (2013) studied disastrous rocks slide in Laipuitlang area, Aizawl which claimed 17 lives and also causes damage and losses of several residential houses. They found out that the main reason which causes rockslides is due to soft and hard porous rock intercalation bedding, steep slope, heavy rainfall, road cutting along dip direction of rock formation and overburden of heavy concrete building in the crown area.

Lallianthanga et al (2013) used the scheme of giving weightages by National Remote Sensing Agency (NRSA, 2001) and stability rating as devised by Joyce and

Evans (Joyce and Evans, 1976) combined for Hazard zonation mapping in Mamit town, Mizoram and also made remedial suggestions.

Lalramdina (2019) observed that human activities coupled with natural factors like lithology, slope, geological structure, rainfall, and physical footprints such as buildings, infrastructure and road cutting have made many parts of Serchhip township highly prone to landslides.

Lawmkima *et al*. (2011) carried out Landslide study in Sairang locality near Aizawl with geomechanical analysis and they stated that landslide in the study area was due to presence of bedding shears and clay beds which bear swelling and shrinkage properties.

Kuldeep et al. (2021) established that erosion at the slope's toe zone is linked to the majority of slope failures that cause landslides. Thus, preventing such landslides may be made easier by reinforcing the slopes' toe areas using gabion walls or RCC retaining walls. Because RCC retaining walls are more resilient and successful at avoiding landslides than other techniques, it is imperative that areas at risk of landslides have RCC retaining walls.

Kumar et. al., (1996) studied the problems of instability al South Hlimcn Quarry site in Mizoram. They were of the opinion that the acute instability problem in South Hlimen Quarry is stemming from two main factors, viz., (i) large size of individual blocks and (ii) the smooth joint surfaces. The tropical climate and heavy rainfall might ha vc caused an additional decrease in the cohesive strength of the joint planes. Furthermore, shaly intercalations between sandstone beds might have provided active slippage surface of failure.

Naithani (2007) carried out Macro landslide hazard zonation mapping using univariate statistical analysis in a part of Garhwal Himalaya. He found out that the geological structures and lithology contributed to more than 72 percent of all the observed landslides in this part of Himalaya.

Moirangcha et.al, (2014) made an assessment of Aizawl city based on seismic and landslide hazard by combining different factors like geological, geotechnical and geophysical and these factors are integrated into the GIS platform. 1:25000 scale was used in this work and modified BIS guideline of GSI (2005) classified that 5% of the study area is in high hazard, 41.3% of the area is within moderate hazard and 53.7% of the area is under low hazard. Also, with integration of seismic, GIS platform generated assessment map using different parameters, this map revealed that 13% very high hazard ,39.1% high hazard and 42.3% moderate hazard and 5.6 % low hazard respectively in the study area.

Raju et. al., (1998) made Landslide Hazard Zonation studies in southern part of Mizoram. They made preliminary Hazard Zonation Map of 6,700 sq.km area. According to their estimation about 10 percent of the area falls within the High Hazard Zone, 60 percent area in Medium Hazard zone and the rest 30 percent falls in the Low Hazard Zone.

Sarkar et al. (1995) developed a methodology of LHZ for Rudrapeayag district in Garhwal Himalayas, India. Numerical weightages are assigned to causative factors on the basis of their relationships to the landslide frequency. Finally, the data layers were overlaid to produce LHZ map.

Tiwari and Kumar (1997) studied South Hlimem quarry area landslide in 1992 which is 7 Km south of Aizawl. This landslide has claimed more 100 lives and made the area unsafe till today. The found that the blocky nature of sandstone and uncontrolled cutting of the slope with blasting led to the failure of this slide.

Tiwari *et.al.,* (1*998*) accomplished Landslide Hazard Zonation mapping along Hnahthial - Hrangchalkawn road section in Lunglei district of Mizoram. They mapped 104.32 sq.km of the area on the up and down hill slopes along this road. The map they generated are divided into low hazard, medium hazard and high hazard zones study areas.

MIRSAC (2008) had carried out Micro Landslide Hazard Zonation Mapping of Aizawl City using Satellite Remote Sensing and GIS technology on 1:30,000 scale.

MIRSAC (2011) carried out micro- level hazard zonation using satellite data generated from Cartosat V stereo pairs, Quickbird with 0.6 m resolution, survey of India topographic maps and other ancillary data and they classified micro hazard landslide zonation into five zones such as very high, high. moderate, low and very low, micro-level landslide hazard zonation map cover Aizawl city and other selected towns.

Varnes DJ (1978) stated that critical slope collapse is caused by precipitation and an ongoing build-up of pore pressure. The region's rainfall threshold is established by the least amount of precipitation necessary to cause a landslide.

Weidner et al. (2018) a precise rainfall forecast that enables the issuing of early warnings based on the area's rainfall threshold is crucial for reducing the danger of rainfall-induced landslides.

CHAPTER III METHODOLOGY

3.1 INTRODUCTION

The methodology adopted for landslide hazard zonation is an attempt to map the hilly terrain in relation with the instability and to assist the sustainable planning for future development. The hazard map presents five-fold classification of degrees of instability which can be used in terrain evaluation (Sarkar, et.al., 1995). The main objective of this research is to produce landslide hazard zonation map by using the heuristic approach in Geomorphic information system (GIS) Environment. In recent years many improvements have been developed for recognizing the landslide occurrences. The combination of the satellite imagery and digital elevation model can be used to detect landslide sites (Barlow et al, 2006). For the study of landslides especially in a hilly terrain like Mizoram, instead of conducting the direct mapping, it would be more reliable to use remote sensing and GIS methods. The advantage of GIS technology with the heuristic approach, statistical analyses, physical based modeling approach, the probalistic approach and database processing provide the necessary tools for supporting landslide hazard zonation map. These processes have been implemented by several researchers and are used to determine the relationship between slope failure and causal factors to generate the landslide hazard zonation map (Zhou et al, 2003).

The landslide hazards and related concepts are based on the definitions provided by Varnes (1984):

- The risk of a landslide occurring in a given area due to local terrain conditions is referred to as the landslide susceptibility. The susceptibility does not consider the likelihood of occurrence, which is also dependent on the occurrence of triggering factors.
- The potential for a damaging landslide to occur within a given region is referred to as landslide hazard. The landslide hazard is composed of three components namely spatial probability, scale probability, and temporal probability.

The present work utilizes the standard procedures of Satellite Imagery interpretation and GIS techniques for preparing the thematic information ultimately transform in to the different form of maps.

The methodology is basically a systematic procedure evolved to assess the landslide susceptibility of the study area using remote sensing data and GIS techniques in conjunction with limited field work. Various steps involved in the methodology are furnished as shown in the form of a flow chart in the figure 3.1.

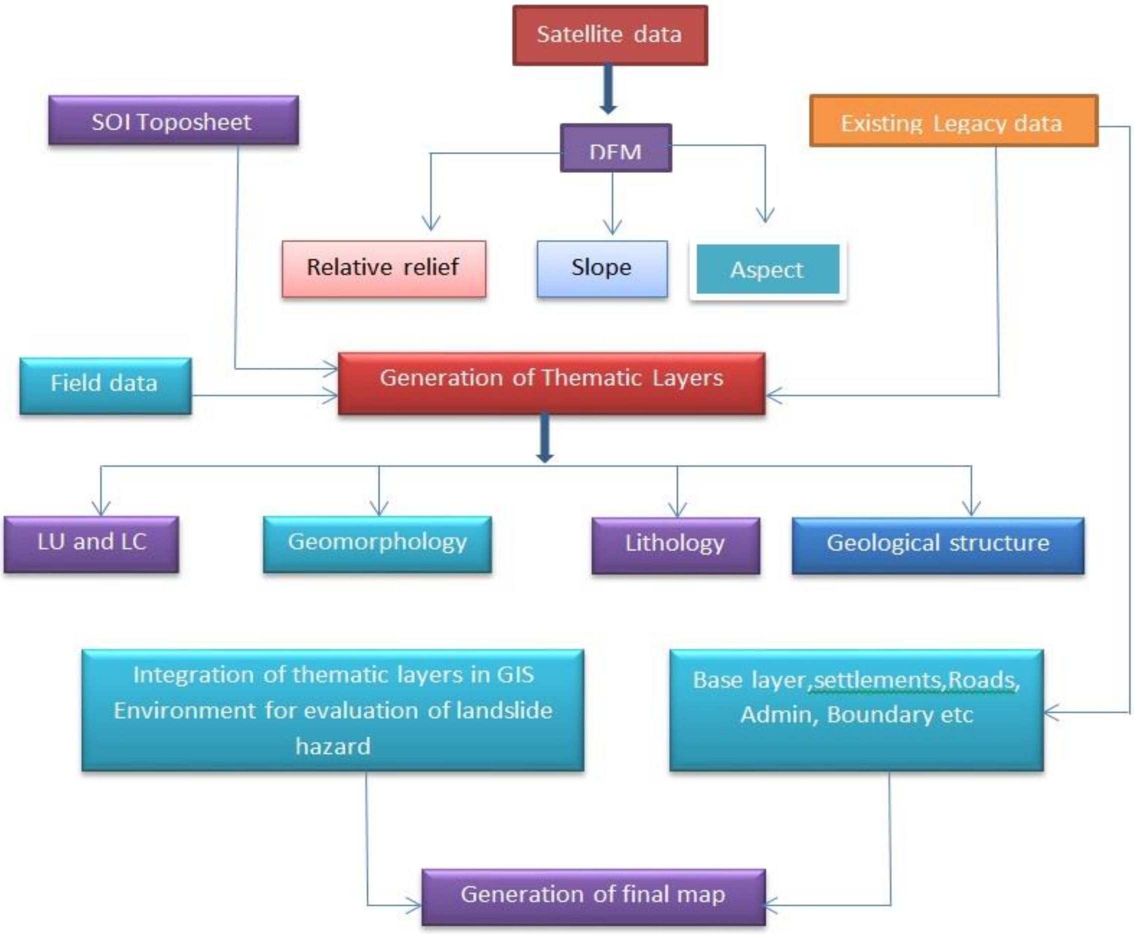


Figure 3.1: Flow chart showing the methodology for the landslide hazard assessment.

The methodology can be divided into two main parts. The first part deals preparation of individual thematic maps i.e. lithology, geomorphology, geological structures and base map details based on the visual interpretation of satellite data and Survey of India Topographic map in conjunction with limited field / existing data.

The second part deals with the derivation of landslide hazard map by integrating the thematic data. The methodology was adopted from Landslide hazard zonation project carried out by National Remote Sensing Agency in 2001.

On-screen interpretation of data*:* The input satellite data, toposheets and geo-reference GSI map, etc. in digital format are displayed on to a screen of the computer system and the generation of different thematic information such as geomorphological, lithological, structural and hydrological information besides the base map details are mapped based on on-screen visual interpretation by using the image interpretation techniques. The interpreted data are cross-checked and corrected with ground truth information collected during the limited field work mandatory.

Resultant output from this will be in vector format, comprising of point, line and polygon features, which supports complex GIS analysis.

The landslide susceptibility assessment offers crucial information for determining the risk of landslides. Landslide inventories and susceptibility maps are important in landslide-prone areas throughout the country (Spiker and Gori, 2000). The aim of the landslide susceptibility map is to identify areas that could be impacted by landslides in the future due to natural or human-caused factors. These maps must be adequately accurate to help local mitigative measures.

Thematic mapping: All the data pertaining to the factors controlling the occurrence of landslide are mapped in the form of thematic layers. All the relevant elements for understanding the ground conditions are systematically studied and considered in an orderly manner for mapping and even missing of one element may also leads to erroneous conclusions.

i) Base map layer: It consists of four categories of information. They are –

a) Administrative

b) Settlements

c) Road network

d) Drainage

The administrative units are mapped as polygon shapefiles, the settlements are mapped as point shapefile, the road and the drainage networks including railway lines are mapped as separate line shapefiles.

The landslide susceptibility mapping approaches can be classified into three cate gories in general namely qualitative, semi quantitative and quantitative (Lee and Jones, 2004). The qualitative approach is a subject-oriented method that works well over broad areas, while the quantitative method is an object-oriented method that looks for a connection between environmental variables and previous landslide occurrences. The researchers who have developed several approaches based on those techniques, such as heuristic approach by Ruff and Czurda (2007), statistical approach by Carara et al (1991), deterministic by Soeters and Westen (1996) and probabilistic approach by Guzzeti et al (2005).

ii) Geomorphology layer

All the landforms / geomorphic units occurring in the study area are mapped as polygon features. They are annotated with their respective geomorphic nomenclatures. While demarcating the geomorphic units, the toposheets were consulted to comprehend the relief variations and other topographic features. The geomorphological map showing assemblage of different landforms is then prepared based on the lithological map so that each rock type is classified into different geomorphic units / landforms.

iii) Lithology layer

All the rock formations occurring in the study area are mapped as a layer consisting of polygon features and are annotated with respective litho-stratigraphic nomenclature using the names of common rock types viz sandstone and shale.

With this “priori knowledge”, the satellite imagery is studied to correlate the different image characteristics with different rock types. Where contrasting rock types are occurring, the boundaries can be seen very clearly on the satellite imagery with different tones or landforms. In other cases, complementary evidences are considered to demarcate the boundaries between different rock types.

iv) Structural layer

The geological structures occurring in the area like faults, fracture/ lineaments etc., which act as weak zones or susceptible zones are mapped as layers consisting of line features.

The methodology deals with the delineation of landslide hazard classes considering parameters influencing the hazard. It consists of preparation of individual thematic maps i.e. geomorphology, lithology, structures and base map based on the visual interpretation and extraction from satellite data in combination with existing data.

3.2 Heuristic approach

The heuristic approach is based on opinion of geomorphology experts. The key input for deciding landslide hazard zonation is the landslide inventory map, which is followed by environmental factors, and then the experts determine the weightage value. Heuristic approach takes into account a hierarchical level and different approaches for determining weightage factors. Next, the hierarchical heuristic model becomes a part of decision support system (DSS) which aims for spatial decisions (Castellanos and Van Westen, 2003). Generally, this approach can be divided into two parts, direct mapping analysis and qualitative map combination. In the direct mapping analysis, the geomorphologists determine the susceptibility in the field directly, which is based on their field based experience. In the later analysis, the experts use their knowledge to determine the weightage values for each class in each parameter. The main problem of this approach is in determining the exactly weightage value because this approach is mainly subject oriented method.

3.3 Statistical approach

The statistical approach to landslide susceptibility assessment has been extended to produce a higher degree of objectivity in landslide hazard assessment (Van Westen, 1993). When past landslide events are absolutely necessary to predict the possible landslide areas, and the key to this approach is a landslide inventory map. The combinations of causal factors are statistically calculated, and quantitative estimations of landslide occurrences are created for currently landslide-free areas based on similar established conditions (Soeters and Van Westen, 1996). In the statistical method, there are two types of analyses: bivariate and multivariate statistical analyses.

3.4 Physical based modeling approach

The landslide hazard assessment is determined by using slope stability model. In contrast to other methods, this method calculates the safety factors to provide a quantitative stability index. There are some hindrances with this approach. The difficult in calculating the safety factor, the extensive datasets needed, and the measurement of the parameter's spatial distribution are all obstacles to this approach (Van Westen et al., 2005). Van Westen (1993) stated that during the input data, such as ground water level, soil profile and geotechnical inputs are insufficient, it can only be applied on a wide scale and over a small region with medium scale. The safety factor values obtained cannot be used as absolute values since they are only used to measure various conditions of slip surfaces and ground water depth. Only when the geomorphologic and geological conditions across the entire research area are reasonably homogeneous and the current landslide forms simple type (Soeters and Van Westen, 1996).

This method relies on the interpretation of remote sensing data, field observations, personal field interactions with local people and historical analysis of landslides in the study area (Soeters and Van Westen, 1996). It is called a simple form of landslide hazard zonation since the resulted spatial distribution of landslide occurrences shows the location of each type of landslide. The result does not present estimate of temporal changes in landslide distribution, which is a imperfection in this method. The flaw in this strategy is that the outcome does not provide an estimate of landslide distribution shifted over time. The landslides that have occurred prior to the field information gathered could be unpredictable. As a result, landslide inventory maps should be generated by using a multi-temporal analysis of satellite data with the aerial photo interpretation (Van Westen, 1993). Although this method does not investigate the relationship between landslides and causative factors, it can be used to qualitative estimation of the landslides.

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 WSG1984 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 1:50,000 scale.

3.6 Data acquired

The accessible data such as literature on landslides and the meteorological data are collected from different sources during the pre-field work. The MIRSAC (Mizoram Remote Sensing Application Center) data was used for interpreting the satellite imagery of the study area. The satellite imagery is geo-referenced and the base maps for different themes generated from the Survey of India (SoI) toposheets on 1:50,000 scale. The image processing software is used to perform the image classification and the pre-field analysis by using ArcGIS.

Preparation of the following thematic maps which was generated on scale 1:50000.

i) Geomorphology and Lineament map

ii) Slope, Aspect Map and Contour Map

iii) Land use/land cover map

iv) Drainage map

v) Lithology and structural map

The collection of landslide inventory data for landslide hazard zonation is from spatial and temporal landslide information from archives, temporal satellite imagery interpretation and the data transformed either in to grid cells, terrain units, slope units or in to topographic units (Reichenbach et al., 2018; Guzzetti et al., 1999). The main goal of the combining various data sources is to get more reasonable results when evaluating a variety of environmental issues (Archana and Kausik, 2013). The total of eight thematic maps generated based on the satellite imagery interpretation and followed by field confirmation of the interpreted results.

3.7 Geospatial techniques

The term ‘Geospatial technology’ refers to the technology used in visualization, measurement and analysis of earth’s features, typically involving such systems as Global Positioning System (GPS), Geographical Information System (GIS) and Remote Sensing (RS). All these systems were employed for generating the reliable information in the selected area under investigation.

Geographic Information Systems (GIS) are computer-based tools used to collect, store, manipulate and display spatially-referenced information. They are used to support decision-making in a wide variety of contexts, including spatial planning and environmental management. GIS is a computer based integrated database management system that stores a large volume of spatial data along with its attribute or non-spatial data which are captured, retrieved, processed and analyzed to provide queries of a geographical nature when required. The GIS technology integrates common database operations such as query and statistical analyses with the visualization of the geographic information through generation of maps. These abilities distinguish through GIS technology and make valuable information for a wide range of public and private enterprises to analyze the events with the planning strategies. (Reddy, et al., 2013).

The present study utilizes the standard techniques of geo-spatial technology for generating the thematic information, which are finally represented in the form of digital layers. The information generated through Remote Sensing and GIS technology are accurate by using the standard methodology accepted everywhere. The methodology adopted in each phase of the work should comply with standard data collection procedures so that both the spatial and non-spatial data correlated at the final stage of product generation. Keeping this in mind, the methodology adopted for the present study has been divided into three phases, viz. Pre-field, Field and Post-Field works.

3.8. Pre- field work

During the pre-field work available information like literature, maps, socio-economic data, meteorological data are collected from various sources. Satellite imageries of the study area are also acquired. The satellite imagery is registered with respect to Survey of India toposheets, and the base maps for different themes are generated. The digital classification the data and the pre-field interpretation are carried out by using the Geographical Information System software through Arc Info platform. The various thematic layers such as lithology, geomorphology, drainage, contour map, slope map, land use and land cover prepared based on the interpretation of satellite data with the available collateral data are also used in the generation of preliminary/Pre-field maps utilized for field verification.

3.9 Field work

The field work or ground truth collection is a very important aspect after the interpretation of satellite imagery for various thematic maps generation. The available ground information is collected during the field work and the pre-field interpreted maps also verified and corrected based on the ground truth verification. The hand-held GPS is used for mapping the locational information of the different selected features interested in the field. The field verification or ground truth collection is an essential part of the interpreted satellite imagery. The important ground truth data was collected during the field visit and the doubtful features mentioned while interpreting the satellite image through pre-field maps preparation were conformed in the field work. All the landslide sites within the study area were recorded with hand held GPS.

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 of landslide disaster 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, 2001). 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 Arc GIS 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., 1999).

3.12 Slope aspect

The slope aspect map is being created for the present research 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 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 plant kinds and rainfall, may influence 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 on topographic sheets from the Survey of India and satellite imagery. For representational purposes, the map has been scaled down to 1:25,000 scale. The proximity of faults was created using 50-m buffer zone. For this research, a lithological map of the study region was created. The lithological map's vector layer was transformed to a raster layer for interoperability with other raster as required by the weighted overlay tool in the ArcGIS programme.

CHAPTER IV – GEOLOGICAL SETTING AND LANDSLIDES

4.1. Regional tectonics and Geology

The North eastern part of the Indian subcontinent, the State of Mizoram and, is an actively deforming transgressional plate margin and associated fold-thrust belt that is generally referred to as the Indo- Burmese fold thrust belt or the Arakan - Yoma (Gannser,1964; Brunnschweiler, I974). In fact, the Mizoram Hills of Mizoram State are located along the central sector of this arcuate, westward-convex deformation 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. In addition, satellite image interpretation and published tectonic maps of the Indo-Burmese thrust belt (Brunnschweiler, 1974; Pivnik, *et al.*, 1998) 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 originally low-angle thrust faults, and a "foreland' fold belt defined by detachment tectonics and associated fold-trains and fault-propagation folds. 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.

North of the Brahmaputra Valley, the Eastern Himalaya define the complexly deformed northern margin to the Indian subcontinent that has undergone several hundred kilometers of tectonic shortening since the initial 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 and Eurasia (Gansser, 1964), 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 (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 defined by the Indo-Burmese ranges and the Indo-Burmese or Arakan Yoma-Nagaland 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, Surma, and Bay of Bengal basins 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, continental arch to the north and the Indian craton of Bangladesh to the south, respectively. 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 Nagaland 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 tertiary sub-basin within the greater Bengal Basin (Ferdous and Renaut, 1996; Mannan, 2002). The Surma basin is a Neogene outer arc basin that exposes alternate arenaceous and argillaceous sequences as rhythmites, showing epeirogenic movements during deposition (Sarkar and Nandy, 1976). Evans (1932) coined the term "Surma Series" after the Surma River in Bangladesh's Sylhet area (Dasgupta, 1982). The Surma basin is defined by a sequence of north-south trending (N15°E to S15°W) sub parallel enechelon regional anticlinal ridges and synclinal troughs. The oblique sinking of the Indian plate beneath the Burmese plate has resulted in the formation of an accretionary prism complex that is migrating westward. The post-Barail unconformity borders the Neogene Surma basin, which is then faulted to the east by the Kaladan fault (Ganguly, 1983). The northern and north eastern limits are defined by the E-W trending Dauki fault and the NE-SW running Disang thrust, respectively. To the west and north west of the Surma basin, the NW-SW Sylhet fault (Nandy, et.al.,1983), also known as the 'HailHakula' lineament (Ganguly,1983), and the Barisal- Chandpur high (Sengupta,1966) are located to the south, the basin extends all the way to Myanmar's Arakan coast.

The Surma Group and newer sediments appear as a westerly convex N-S fold belt with a strike length of around 550km and a maximum breadth of 200 km inside this enormous landscape. The Surma basin includes the Assam districts of Cachar and Karimganj, Tripura and Mizoram, the western part of Manipur, Bangladesh's districts of Sylhet and Chittagong, and Myanmar's Arakan coastal zone. The Indo Myanmar mobile belt’s highly folded, faulted, and thrusted Palaeogene outer arc complex lies to the east of this basin, whereas the alluvium-covered, gently dipping, homoclinal tertiary sedimentary sequence of Bangladesh occurs to the west, and adjacent to the Bengal basin (Nandy, 1972). This took on a ‘bell shaped' shape, with a continual southerly and south-westerly paleo-slope connecting to the open sea to the south.

La Touche (1891) initiated mapping the Mizoram basin, which extends along the eastern and south-eastern boundaries of the Shillong Plateau, and was continued by Mathur and Evans (1964) and Ganguly (1983). Due to the terrain's inaccessibility, detailed field traverses were limited. Ganguly (1974, 1975, &1983), Shrivastava, et.al. (1979), Nandy (1972,1980, &1982), and Jokhanram and Venkataraman (1984) Mapped the area on a regional basis using aerial pictures. The Geological Survey of India (GSI) has completed regional mapping of several parts of Mizoram at a scale of 1:50,000

4.2. Surma group

The Surma Group is widely exposed in Mizoram and is called after its type area in Surma valley (Evans, 1964). It is made up of varying proportions of poorly fossiliferous shale, mudstone, sandstone, and siltstone, as well as a variety of facies with alternating ridges and valleys. Mizoram is the epicenter of the Surma group of rocks, which span over 8000 meters in thickness (Table 4.1). The Surma Group is divided into the Upper, Middle, and Lower Bhuban Formations, as well as the Bokabil Formation (Fig. 4.1). The studied region is dominated by the Middle Bhuban formation, with some Upper Bhuban formation present in several places. Because of the periodic deposition of sandstone, shale, siltstone, and mudstone of varying thickness and proportions, the Surma Group of sediments shows intergrading and inter-bedding.

The general deposition events in the Surma basin consists repetitive successions of mainly Neogene arenaceous and argillaceous sediments. The present lithostratigraphic sequence of Surma basin (Nandy, et al.1983) has broadly been subdivided into the Surma group (Miocene), the Tipam group (Pliocene) and the Dupitila group (Pleistocene). It comprises of alternations of poorly fossiliferous shale, mudstone, siltstone and sandstone in a varying proportion with rapid lateral variation of facies and is characterized by alternate ridge and valley topography. The Bhuban super group has been named after its type area of Bhuban range in the western Manipur Hill and is well developed in Mizoram.

The Neogene sediments of Surma basin cover entire Mizoram, as Miocene sediment depo-centre. They are ranging from Barail to Tipam Group but the Surma Group rocks are dominated throughout Mizoram. The Surma group covers about 75%of the territory of the Mizoram state. These sediments are emerged into north-south trending fold belt. This fold belt consists of sub-parallel doubly plunging enechelon anticlinal ridges and synclinal valleys of Barail, Surma and Tipam groups. The Barails are exposed in the eastern border of Mizoram, the Surma group covers central and major part of the state, and the Tipam Group of rocks exposed in the western border of Mizoram. The Barail Group mainly comprises of shale, siltstone and sandstone. The Bhuban Subgroup comprises hybrid association of mudstone, sandy mudstone, siltstone, sandy siltstone, mud-shale and muddy sandstone, showing relative dominance of argillaceous over arenaceous facies. The Bokabil consists of shales with siltstone and sandstone. The Tipam group of rocks comprises friable sandstone with occasional clay bands.

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).

Age	**Group / Formation**		**Thickness**	**Gross Lithology**	**Depositional Environment**
Recent	-		-	Gravel, silts and clays	Fluvial and alluvial
------------------Unconformity-------------------					
Early Pliocene to Late Miocene	Tipam		+ 900 m.	Friable sandstone with occasional clay bands	Fluvial
------------------Conformable and transitional contact -------------------					
Miocene To Upper Oligocene	SURMA	Bokabil	+ 950 m.	Shale, siltstone and sandstone	Shallow marine
		------------------Conformable and transitional contact -------------------			
		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 -------------------					

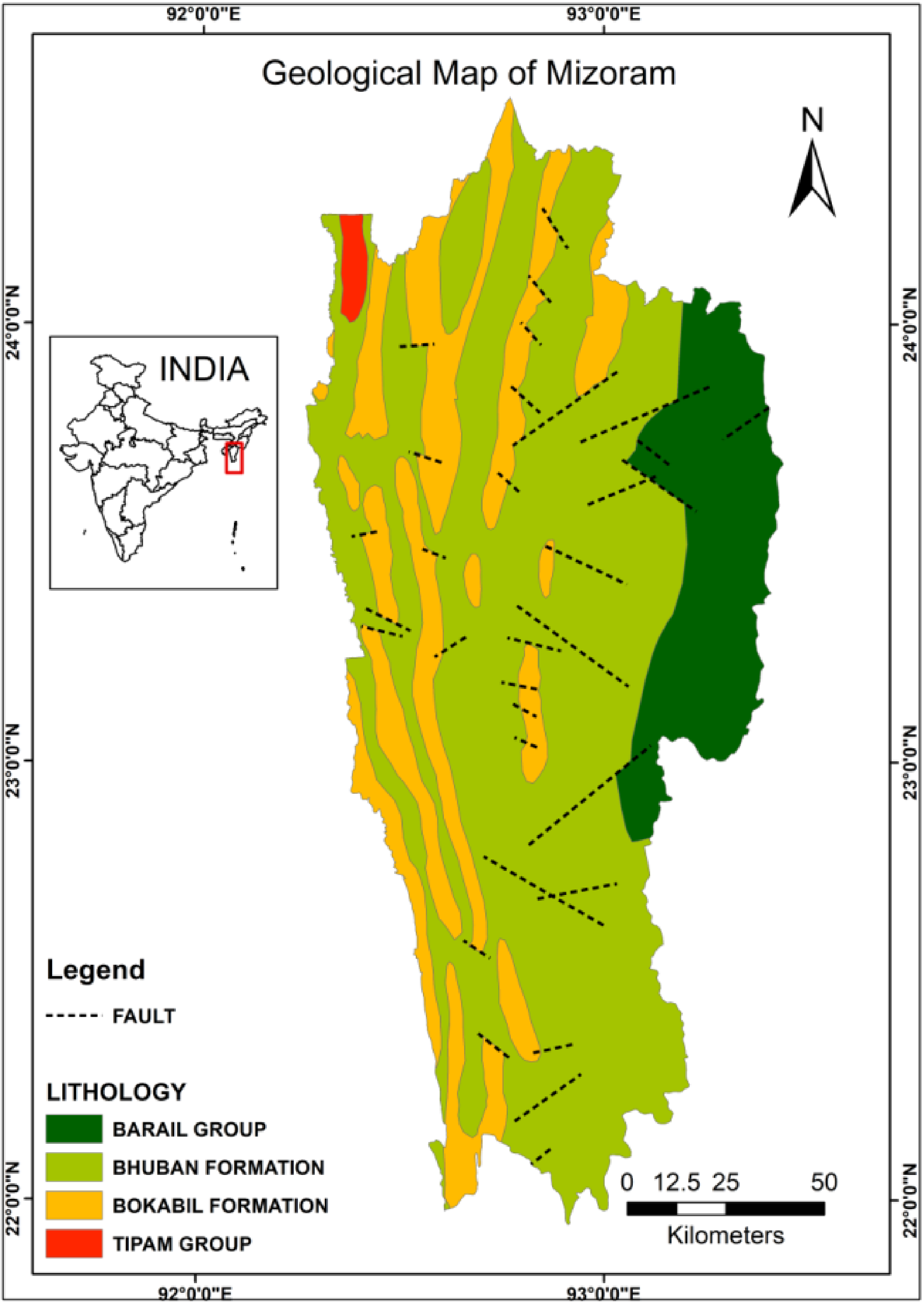


Figure 4.1: Geological and broad structures of faults map of Mizoram (After GSI, 2013; Barman, 2021; Barman and Rao, 2021.

Shales from the basically argillaceous Middle Bhuban are exposed on the limbs of anticlines in the area (Jokhanram and Venkataraman, 1984). Thin lamination, sole markings, warm burrows, ripple marks, and load castings can all be found in the Mizoram basin shales (Jokhanram and Venkataraman, 1984). The layering may not be continuous at times, and one of the layers may taper away. Deformation, including shearing, is visible in shale interlayered with siltstone/grey shale. The varying conditions of deposition are represented by shales, various types of sandstones, grey to dark grey shales, conglomerates, siltstones, laminated mudstone, and claystone. The occurrence of fossiliferous sandstones and diverse primary sedimentary turbidity structures indicate shallow marine to deltaic deposition environment (Holtrop and Keizer, 1970). Based on various fossil records, the Mizoram basin sediments were deposited in a near shore shallow marine environment (Tiwari and Bannikov, 2001).

4.3. Bhuban Formation

Bhuban formation is well developed in Mizoram, primarily in the anticlines, and was named for its type's locality area of the Bhuban range in the western Manipur Hills (Nandy, 2017). The formation is made up of a mix of siltstone, shale, silt-shale, and muddy sandstone, with argillaceous rocks dominating. Intermixtures occur because there is no apparent distinction between finer and coarser clastic sediments. Sand and shale intercalations are prevalent, and the sandstones are mostly hard, fine-grained, and poorly sorted, with frequent facies shifts. The Bhuban group of rocks is distinguished by argillaceous and arenaceous layers that have undergone cyclic sand-shale alteration. The sandstones bed usually shows ripple marks with cross stratifications.

4.4. Upper Bhuban Formation

An arenaceous sequence covers the Middle Bhuban formation. It is typically found in the syncline core sand consists of more than 1200 meters of thinly bedded dark sandstone and shale alteration, which is overlain by bluish to grey medium grained sandstone (Ganju,1975).

4.5. Middle Bhuban Formation

The Upper Bhuban Formation, which is predominantly an argillaceous succession of rock, is underlain by this Formation and consists of a monotonous and thick succession of 3000m of alternating stages of siltstones and shales. The siltstone is usually grey to bluish grey with cross stratifications and mud cracks, whereas the shale is usually grey to dark grey with cross stratifications and mud cracks (Ganju, 1975).

4.6. Lower Bhuban Formation

This Formation is predominantly arenaceous in nature, and it is Mizoram's second oldest lithology, occupying the anticlinal cores of the state's southern region. The sandstone in this formation is moderately to poorly sorted, weathered, and fine grained, whilst the shales are thinly laminated, friable, and dark grey, with a unit thickness of roughly 900 meters (Ganju,1975), which is lower than the other formations.

4.7. Bokabil Formation

The Bokabil formation, which is exposed extensively all throughout Mizoram syncline and is known after its type locality near Bokabil Valley in Hailakandi (Assam). Large facies range from shale to sandstone characterizes them, and they are generally arenaceous with worn patterns. In the upper section of these strata, invertebrate fossils are abundant. This formation's rocks may well be observed in the north western region of Mizoram and have a thickness so roughly 950 meters (Ganju, 1975).

4.8. Landslide history in the region

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 (NDMG, 2009). The region is geologically young, and the lithology is dominated by unstable and soft sedimentary rocks, which are easily prone to sliding down the hill when subjected to heavy rain. In addition, the state’s steep slope and relief, as well as poor land use practices, have increased the frequency of landslides in the region.

Several major landslides have been documented in the Aizawl district over the last two decades. In1992, a landslide in a stone quarry in the South Hlimen area killed 66 people (Tiwari and Kumar, 1996). A total of 17 homes were destroyed. In 1994, the communities of Aizawl Venglai, Ramthar, and Armed Veng sank, causing extensive damage to 65 homes. In1995, a long-line fracture appeared alongside the Aizawl-Sairang Road in the Hunthar neighborhood (National Highway 54). The enormous Ngaizel landslide halted the national highway for many days in May 2011 (Verma 2012 and 2013). In June 2017, flash floods and landslides triggered by torrential rains caused havoc in Tlabung, Mizoram's Lunglei district, killing at least eight people and leaving six more missing. On August27, 2015, heavy rains and landslides in Mizoram's capital city swept away three houses and damaged 70 graves in two cemeteries, houses were swept away by heavy rains and landslides in Mizoram's capital city, while four vehicles were damaged in landslides. Atleast 50 graves were also damaged at the cemetery of Chaltlang locality and due to large landslides on the highways, numerous district headquarters, including south Mizoram's Lunglei, Saiha, and Lawngtlai districts, Serchhip and Mizoram-Myanmar border Champhai district, and remained cut-off from Aizawl. During 2017, continuous rains have caused landslides and floods in Mizoram, killing at least 12 people and destroying 877 structures.

Table. 4.2: List of major landslides in 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	Hunthar veng	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	Tuikhuah veng	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 RESULTS AND DISCUSSION

5.1 Land slide Hazard Zonation and risk assessment

The Task force on landslide Hazard Zonation set up by the Ministry of mines, Govt. of India suggested that the scales of landslide hazard zonation maps should be agreed to bear in mind the purpose for which they are going to be used. The task force defined the three levels of scales for which the purpose of the landslide hazard zonation maps further utilized for the sustainable mitigative measures. The scale on the map 1cm represents 25,000 cm in the ground. Further, the task force has defined the scales which depend on the areal coverage.

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 selection of conditioning factors is often referred to as the selection of attributes also important. In a GIS environment defined by various thematic layers namely geological, morphometry, hydrological and environmental parameters, and by synthetic parameters derived from discretizing, reclassifying or performing statistical operations on inputs.

After the field verification, the pre-field maps are finalized by making necessary corrections and modifications. Various data collected from the field are studied and analyzed. After finalization of the primary layers, the derived layers are prepared by using several primary layers. Area calculation is also done to obtain spatial coverage. Finally, report consisting of the description and landslide hazard map and also the action plan for mitigation of landslide disaster of the study area is prepared.

The majority of the landslides observed and checked in the field were shallow translational debris/rock slides with a slip plane depth of approximately between 2-4 meters. Since the road provides a horizontal foundation for debris accumulation, most landslides occur on the road's upslope and have a very short or no run out distance. No landslide was seen below highway during field work. The present area has face constant rock fall throughout the year due to construction of national high way. The rock falls those are presented in the study area where the shale and sandstone inter-bedded localities. This type of rock formation is prone to weathering and erosion. As shale is weather more easily than sandstone, this may lead to wedging and which fail slowly and led to rock fall. The rock fall area belongs to vertical rock wall and this area also undergone regular rock blasting during widening of the national highway. The blasting effect may have caused fractures and weakening of joint sets present in the area. Hence, rock fall occur throughout the year. Landslide along major highway is a common phenomenon during monsoon period in the study area. Rainfall and anthropogenic activities are the key triggering factors of landslides in the study region. The number of slope failures triggered by rainfall combined with the inherent causative factors is extremely high during the monsoon months. Thirteen landslides were identified during field work and landslides occurred mostly along the highway.

5.2 Results derived from various thematic layers

The generated various thematic layers of the study area has been analyzed and interpreted, the statistics and the maps showing different classes within each factor affecting landslides were generated using satellite imagery by ArcGIS software.

5.3 Geological factors

5.3.1 Lithology

Landslide initiation is influenced by the geological rock formation. The rock unit features of any hill region control slope failure. Because different lithological rocks structures have varying susceptibilities to active geomorphic processes, lithological structure plays an important role in landslide hazard zonation (Pradhan et al. 2007, 2009). The lithology is one of the controlling parameters in slope stability since each class of materials has different shear strength and permeability characteristics (Yalcin and Bulut, 2007). Lithology plays a major role in the slope movements such as rock fall influenced by rock hardness, fractures and the weathering of rocks. The lithology reflects the engineering properties of rocks in the region. The adhesion properties and internal friction angle of the engineering properties of lithology are a lot of impact.

Different rock types have varied composition and structure which contribute to the strength of the slope material in a positive or negative way. The stronger rock units give more resistance to the driving forces as compared to the softer/ weaker rocks.

The resistance of rocks to the weathering and erosion process is the important aspect in controlling the slope stability. The study area includes the Tertiary formations of Bhuban and Bokabil that belongs to the Surma Group, which are made up of primarily arenaceous and argillaceous rocks. Four litho-units have been established for the study area purely based on the exposed rock types of the area. These are referred to as gravel-silts and clays/shales belong to the Bokabil formation, sandstones referred as the Upper Bhuban formation, and the shales belong to the Middle Bhuban formation. The unconsolidated material units have a higher risk of slope collapse than other units; they are assigned the highest weightage value. Siltstone and shale lithological formations are more prone to landslides than hard and compact sandstone strata.

Based on the analysis of Lithological data (Fig. 5.1), shale and sandstone alterations forms majority of the study area with 307.sq.km (60%) shale and sandstones 191 sq.km (37%), pockets of gravel, sand and silt covering a small area of 18 sq. km (3%) (Table 5.1).

Table 5.1: Type of Lithology in the study area.

Lithology	Area in Sq. Km.	Percentage
Gravel, sand & silt (Recent)	18	3
Sandstones belong to the Upper Bhuban Formation	191	37
Shales belong to the Middle Bhuban Formation	247	48
Shales belong to the Boka Bil Formation	60	12
Total	516	100%

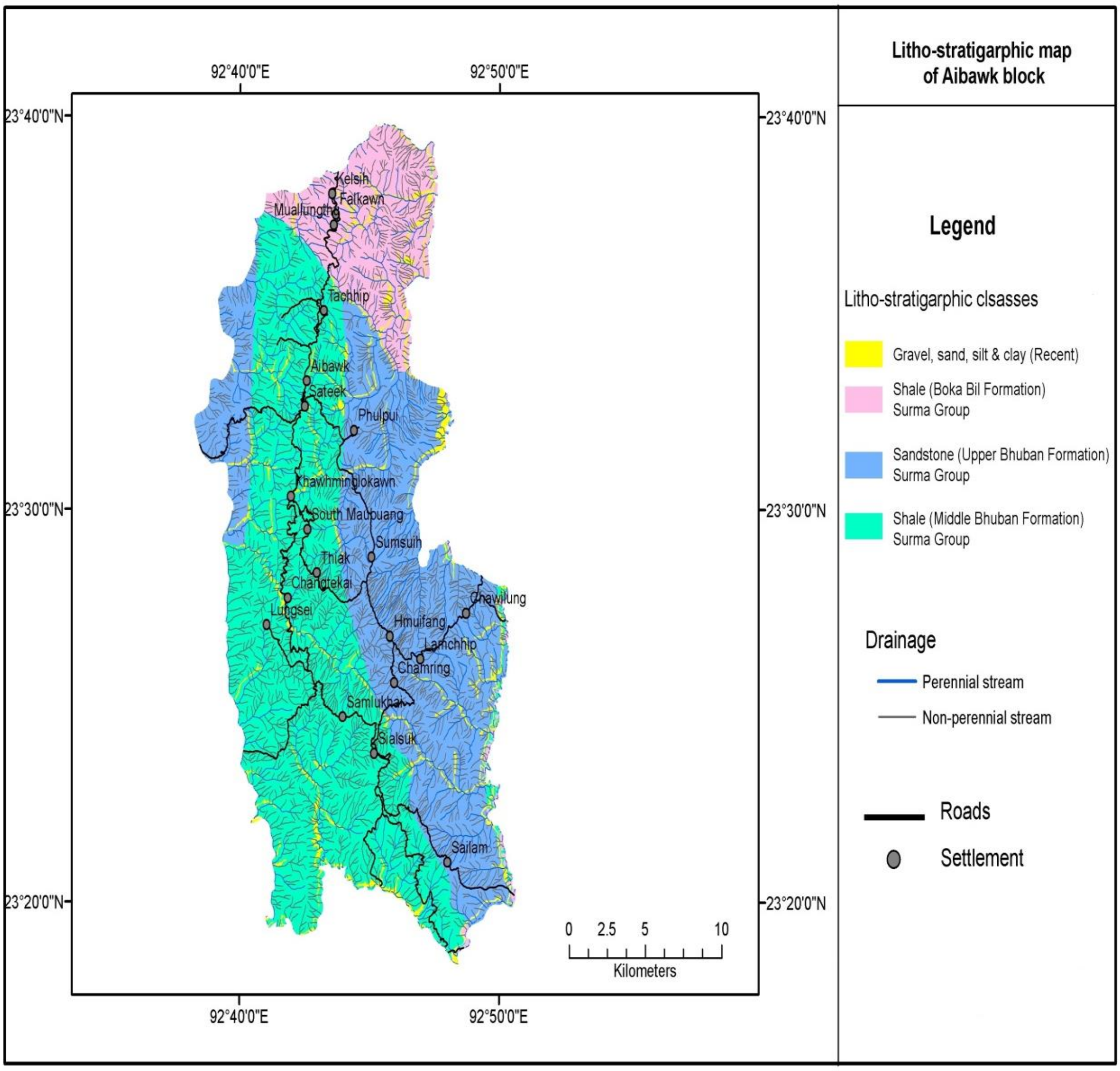


Figure 5.1: Lithology of Aibawk Rural development block.

5.3.2 Geological structure

The tectonic breakdowns such as faults, thrusts, and shear zones are lithological structures that play a significant role in the occurrence of landslides. Because these fractures reduce rock strength, they are considered susceptible landslide initiating sites (Pradhan and Youssef, 2009). 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 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, fractures, and junctions (Kanungo, et al., 1995). The most significant factors for Landslide Hazard Zonation are 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 occurrence of landslides is influenced by the geological formations with the geological structures. The discontinuity connected with the insitu- rocks across hill slopes including bedding planes, joints, foliations, faults and fractures. Slope stability is influenced more by structural discontinuity in relation to slope inclination. The correlation of slope direction and discontinuity parallelism, discontinuity of dip and slope dip direction and also discontinuity of dip. The rocks exposed in the region are pierced by a number of faults and fractures of variable size and length (MIRSAC, 2006). Areas close to fault zones and other geological features are thought to be more susceptible to landslides.

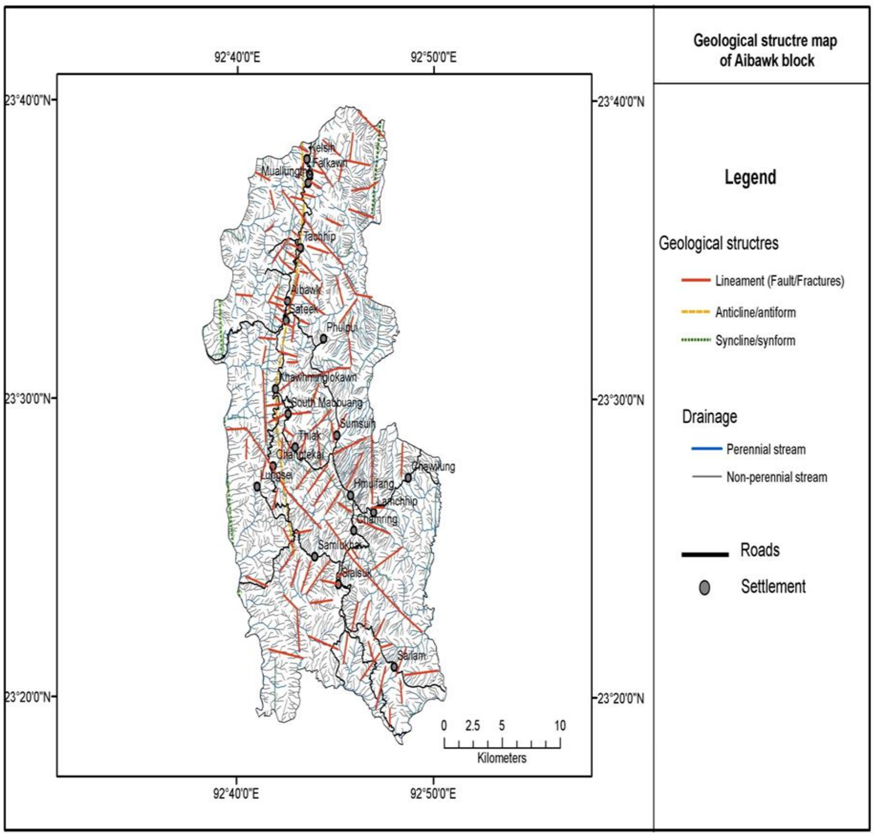


Figure 5.2: Geological structures in the Aibawk Rural Development Block.

5.3.3 Geomorphology

The study area consists of structural hill ranges that are highly dissected, undulating, and moderately sloping. Some of the hillocks are highly dissected, with sharp ridges and steep slopes, while others are gentle and low dissected. This shows that the topography is still in its infancy. A small number of flat plains can be found largely along streams and between spurs. The entire area is divided into four geomorphological categories: high structural hill, medium structural hill, low structural hill, and valley fill. Landslides are more likely to occur in high-elevation locations than in low-elevation areas. The study area is divided into five types of geomorphic classes (Fig. 5.3). Flood plain cover 1%, high dissected area occupies 5%, medium dissected area covers 65%. Low dissected and valley hill cover 28% and 1% respectively (Table 5.2).

Table 5.2: Type of Geomorphology in study area.

Geomorphic Units	Geomorphic classes	Area in square kilometres	Percentage
1.	Flood plain	1.36	1
2.	High dissected	28.404	5
3.	Medium dissected	336.47	65
4.	Low dissected	144.63	28
5.	Valley fill	5.97	1
-	-	516.38	100

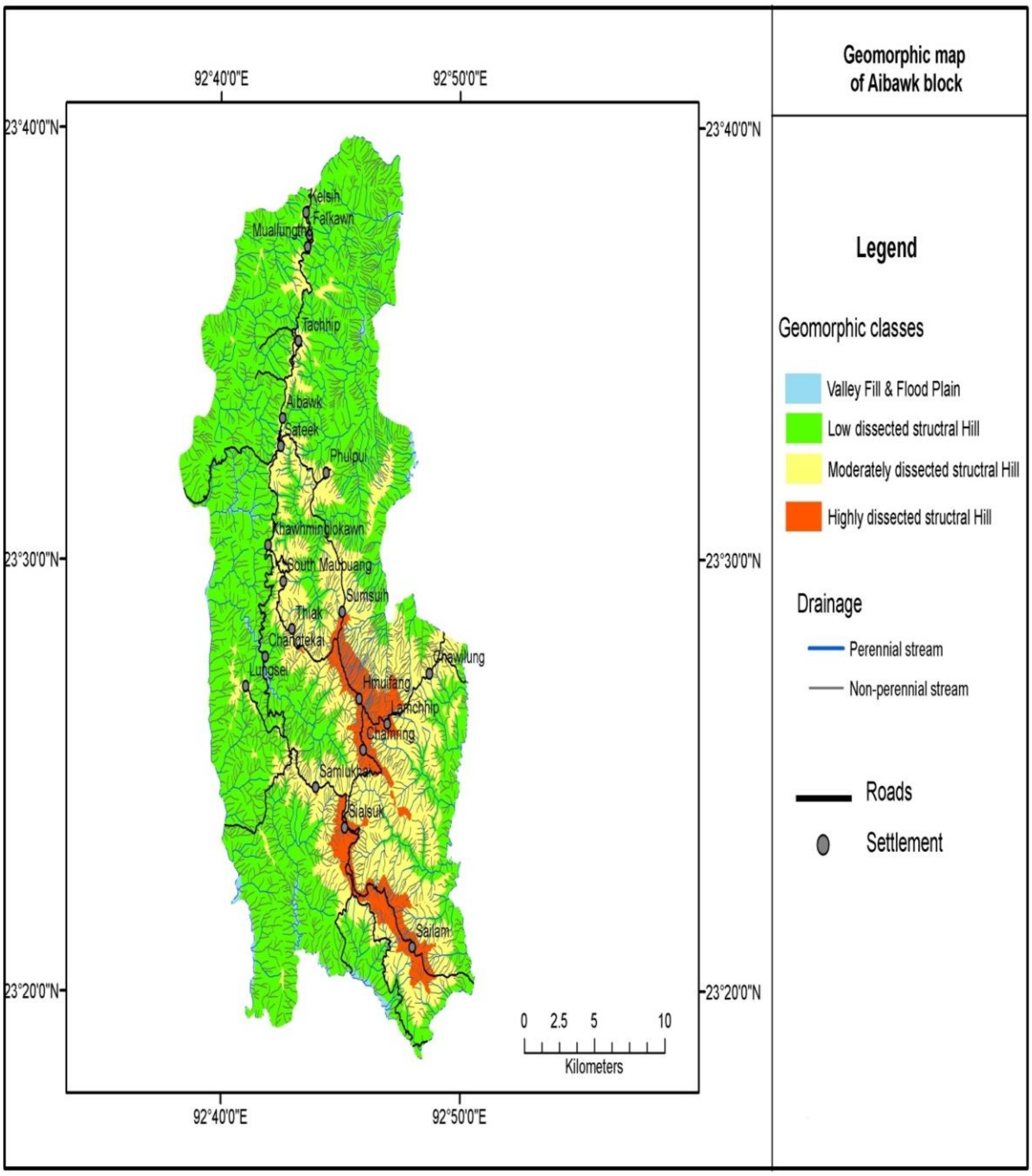


Figure 5.3: Geomorphology of the Aibawk rural development block.

5.3.4 Relative relief

The study area possesses high relative, medium or local relief (Fig. 5.4). The higher values indicate rapid rise in altitude and presence of faults, lower relief signifies mature topography. Relative relief is an important factor in landslide hazard zonation. It plays a decisive role in the vulnerability of settlements, transport network and land (Chandel, et al, 2011). The highest point within the study area has an elevation of 855m from the mean sea level. The whole area was divided into High, Moderate and Low classes in terms of relative relief with 1601m to lowest 400m from sea level. High elevated areas are more susceptible to landslide than areas with lower elevation (Lee, *et al.*, 2004).

Table 5.3: Relative relief map of study area.

Relief Class	Relative relief	Relief Range	Area in square meter	Percentage
1.	High	1400-1600 m	40.90	7.9
2.	Medium	1200-1400 m	239.42	46.36
3.	Low	100-1200 m	236.06	45.74
-	Total area		516.38	100

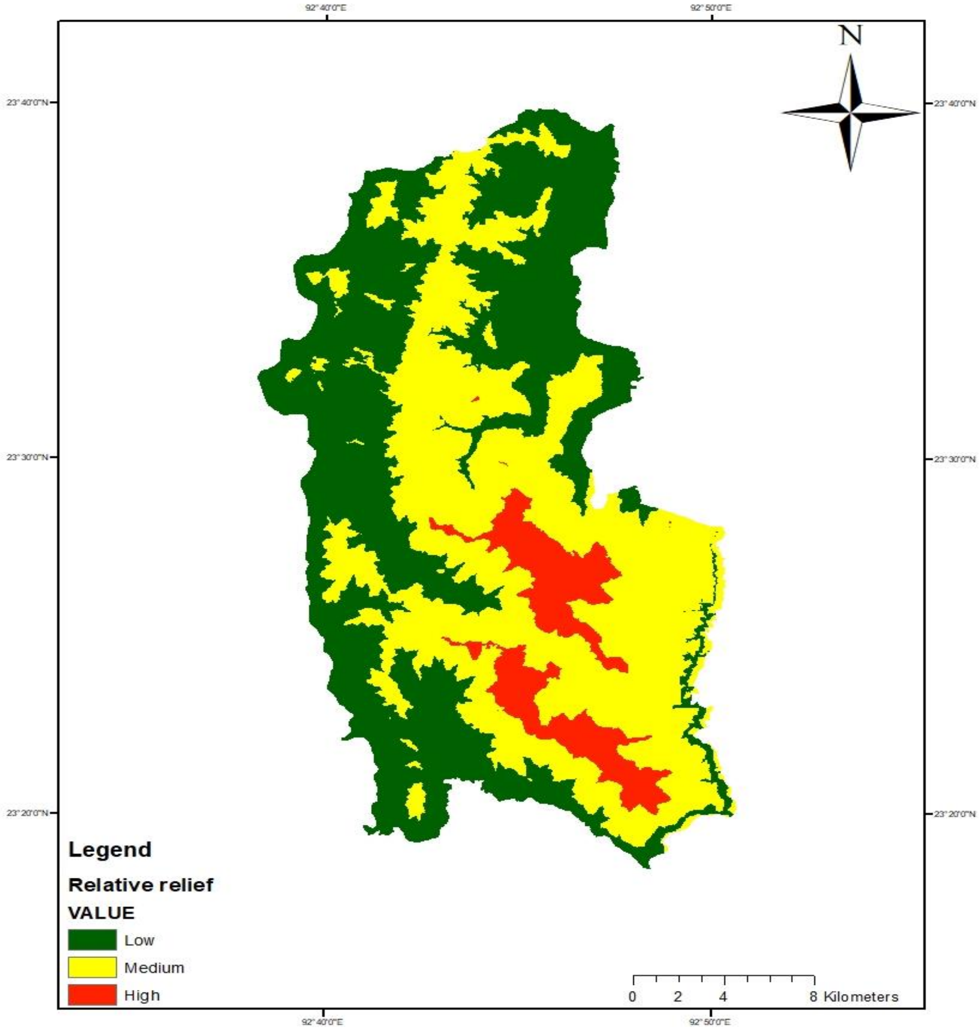


Figure 5.4: Relative relief map of the study area.

5.3.5 Slope morphometry

The slope map is prepared (Fig. 5.5) based on the generated STRM DEM image in the GIS domain for the landslide hazard study in the area. The slope map is categorised into 7 slope category classes (Table 5.4). The slope represented in the study area is in degrees and categorised into seven classes as 1. 0-15^0; 2. 15-25^0; 3. 25-30^0; 4. 30-40^0; 5. 35-40^0; 6. 40-45^0; and 7. > 45^0.

Table 5.4: Types of slopes in the study area.

Slope class	Slope angle	Area in square kilometres	Percentage
1.	0-15	3.77	0.7
2.	15-25	1.10	0.4
3.	25-30	22.43	4.5
4.	30-35	59.52	11.5
5.	35-40	171.95	33.3
6.	40-45	169.56	32.5
7.	>45	88.50	17.1

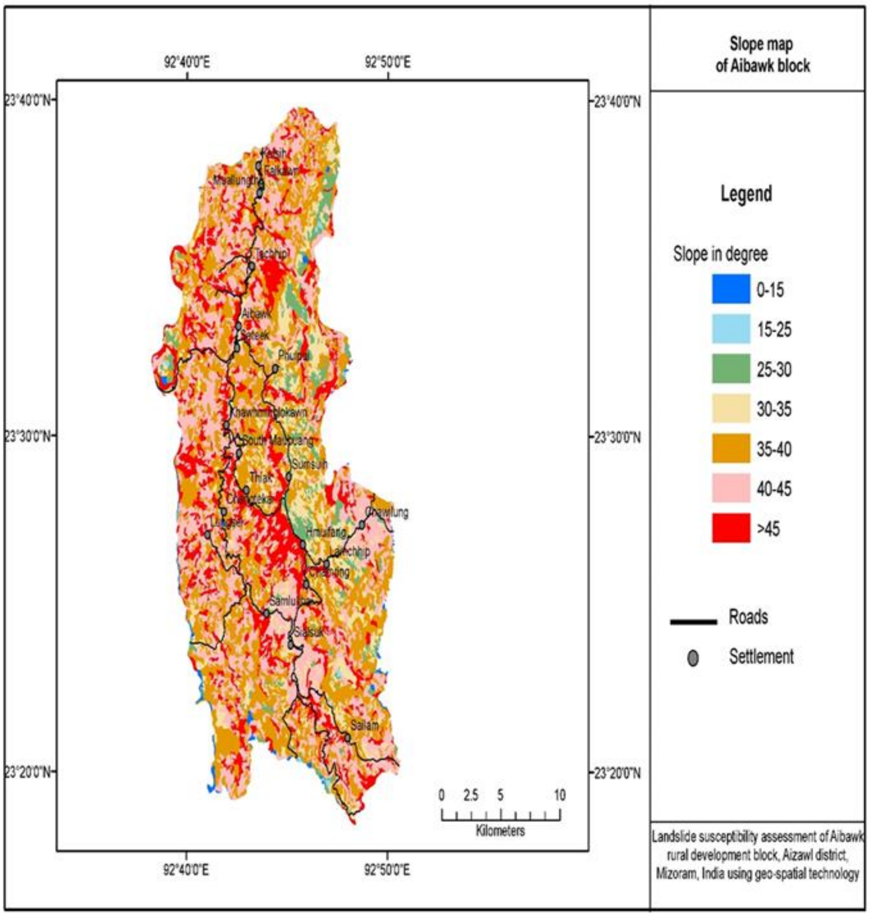


Figure 5.5: The slope map of the Aibawk Rural development block.

5.3.6 Slope Aspect Map

Another important event conditioning characteristic is slopes aspect, which has been studied by a number of scholars (Nagarajan et al. 1998; Yalcin et al. 2011; Pourghasemi et al. 2013; Ghosh et al. 2014). The slope aspect refers to slope orientation which is generally expressed in terms of degree from 0^0-360^0. The slope aspect map of the study area is prepared based on the interpretation of satellite imagery (Fig. 5.6). It is considered as an important factor in landslide studies as it controls slope exposures expose to sunlight, wind direction, rainfall (degree of saturation) and discontinuity conditions (Komac, 2006). Various hydro-meteorological phenomena, such as the quantity of sunlight, precipitation, and the area's topography, influence landslide initiation (Pourghasemi, et al. 2013). The amount of rainfall received on the slope's hillside is related to the slope's alteration capacity, which can be influenced by a variety of factors including the slope's topography, permeability of the rock structure, porosity, moisture retention, organic ingredients, land use, and climatic season (Pourghasemi, et al. 2013). The south facing hill slope of the Himalayan Mountain landscape receives the most rainfall, which is considerably higher than the north facing slope (Ghosh, et al. 2014). The different slope aspect area coverage is shown in table 5.5.

Table 5.5: Types of slope aspects in the study area

Aspect	Area in square Kilometre	Percentage
Flat	37.777954	7.3
North	56.014989	10.7
North east	60.382034	11.6
East	64.16969	12.4
South east	76.409436	14.7
South	56.130607	10.8
South West	60.125704	12.6
West	65.496777	12.6
North west	37.846023	7.3
Total	516.353214	100

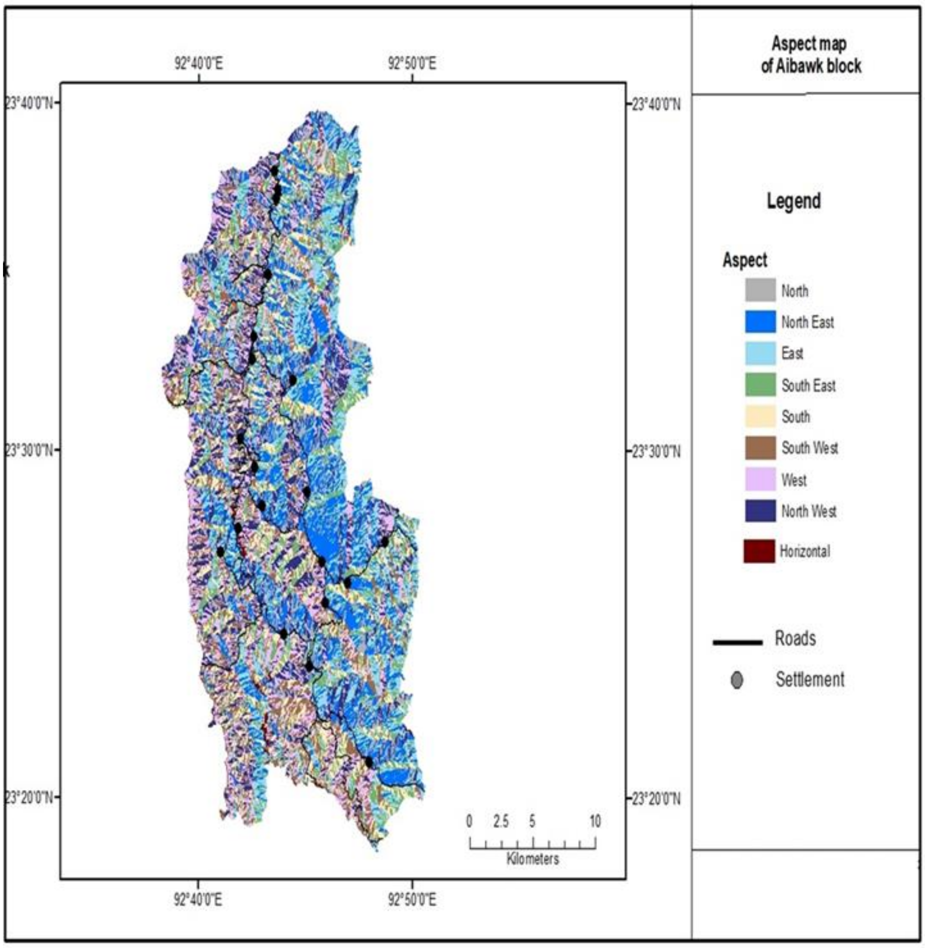


Figure 5.6: The Aspect map of the Aibawk Rural development block.

5.3.7 Topographic map

A topographic map is a map that uses elevation contour lines to depict the form of the Earth's surface features. Elevation contours are fictitious lines that connect locations on the land's surface that have the same elevation above or below a reference surface, which is usually mean sea level. Contours may be used to represent the height and form of mountains, the depths of valleys, and the steepness of slopes.

On topographic 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. Hydrography includes 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.

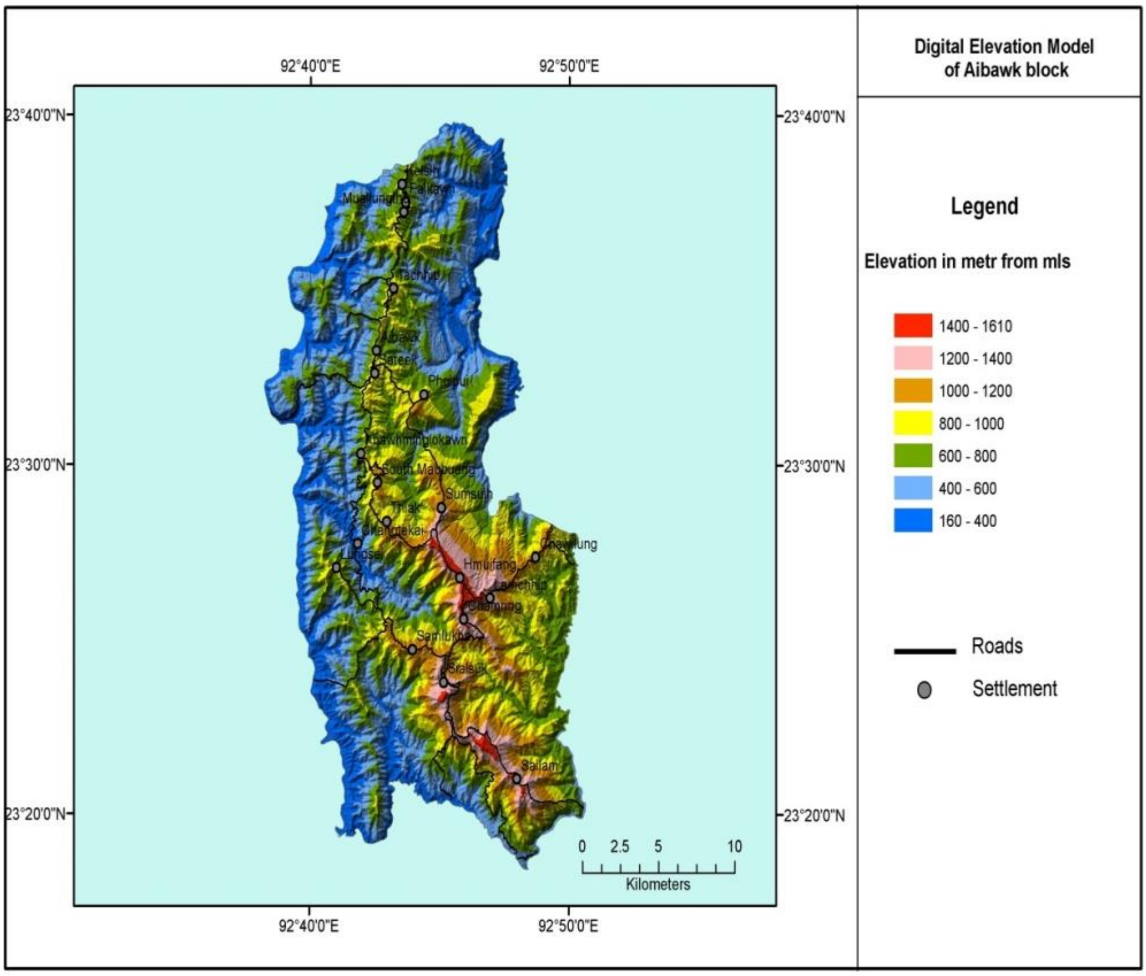


Figure 5.7: The Digital elevation model of Aibawk Rural Development Block.

5.3.8 Land use and land cover

Land-use change has been recognized throughout the world as one of the most important factors influencing the occurrence of rainfall-triggered landslides. Changes in land use/cover resulted from man-made activities such as deforestation, overgrazing, intensive farming and cultivation on steep slope can initiate slope instability (Glade, 2003). Land use land-cover (LULC) pattern is one of the important parameters in controlling the slope stability. Vegetation has major role to resist slope movements, particularly for failure of shallow depth slip or rupture surfaces. Vegetation has a major contribution to resist slope movements. Vegetation having a well-spread network of root systems increases shearing resistance of the slope material. This is due to the natural anchoring of slope materials. In addition to this, it reduces the action of erosion and adds the stability of the slope. In another way, barren or sparsely vegetated slopes are usually exposed to erosion and thus it has the effect of increasing slope instability. Land use has a big impact on landslide initiation. The land cover also affects the slope stability of the area. Slope instabilities can be avoided by long-term vegetative cover. A well-distributed root system increases the shearing resistance of the slope material due to natural anchoring. Furthermore, because the plant's root network takes water from the soil mass to perform metabolic functions such as photosynthesis and transpiration, the moisture content of slope material is kept under control (even during natural precipitation cycles). The hill slopes in the research region area are made up of overburden material like colluvium and/or highly worn mantle of shallow thickness, yet dense vegetation or grass cover might reduce the influence of physical weathering and subsequent erosion, boosting the slopes' stability. Slopes that are barren or sparsely vegetated, on the other hand, are more prone to weathering and erosion, making them more likely to fail. When determining landslide susceptibility mapping, this is one of the most significant aspects to consider. Plant coverings, for example, strengthen the soil by supporting the roots. It offers a lot of potential for reducing slope failure rates (Begueria, 2006). The land use/land cover pattern, which is one of the most important factors affecting slope stability, controls the rate of weathering and erosion (Anbalagan, et al., 2008). In comparison to all other groups, built-up regions were shown to be the most sensitive to landslides (Pandey et al., 2008), while dense vegetation areas were found to be less prone to landslides (Pandey et al., 2008). The study area 0.537% is covered by built up area, 36.251% is occupied by heavy vegetation and moderate vegetation also covers 47.039% (Fig. 5.8) and also the largest area by percentage in the area in land use and land cover categories (Table 5.7). The Scrubland and water body also cover 16.17% and 0.0014%, respectively in the study area.

Table 5.6: Types of land use and land cover in the study area.

LU/LC Classes	**LU/LC type**	**Area in Square kilometre**	**Percentage**
1.	Built up	2.77	0.54
2.	Heavy vegetation	187.10	36.25
3.	Moderate vegetation	242.78	47.04
5.	Scrub land	83.457	16.17
6.	Water body	0.00	0.00
-	Total	516.38	100

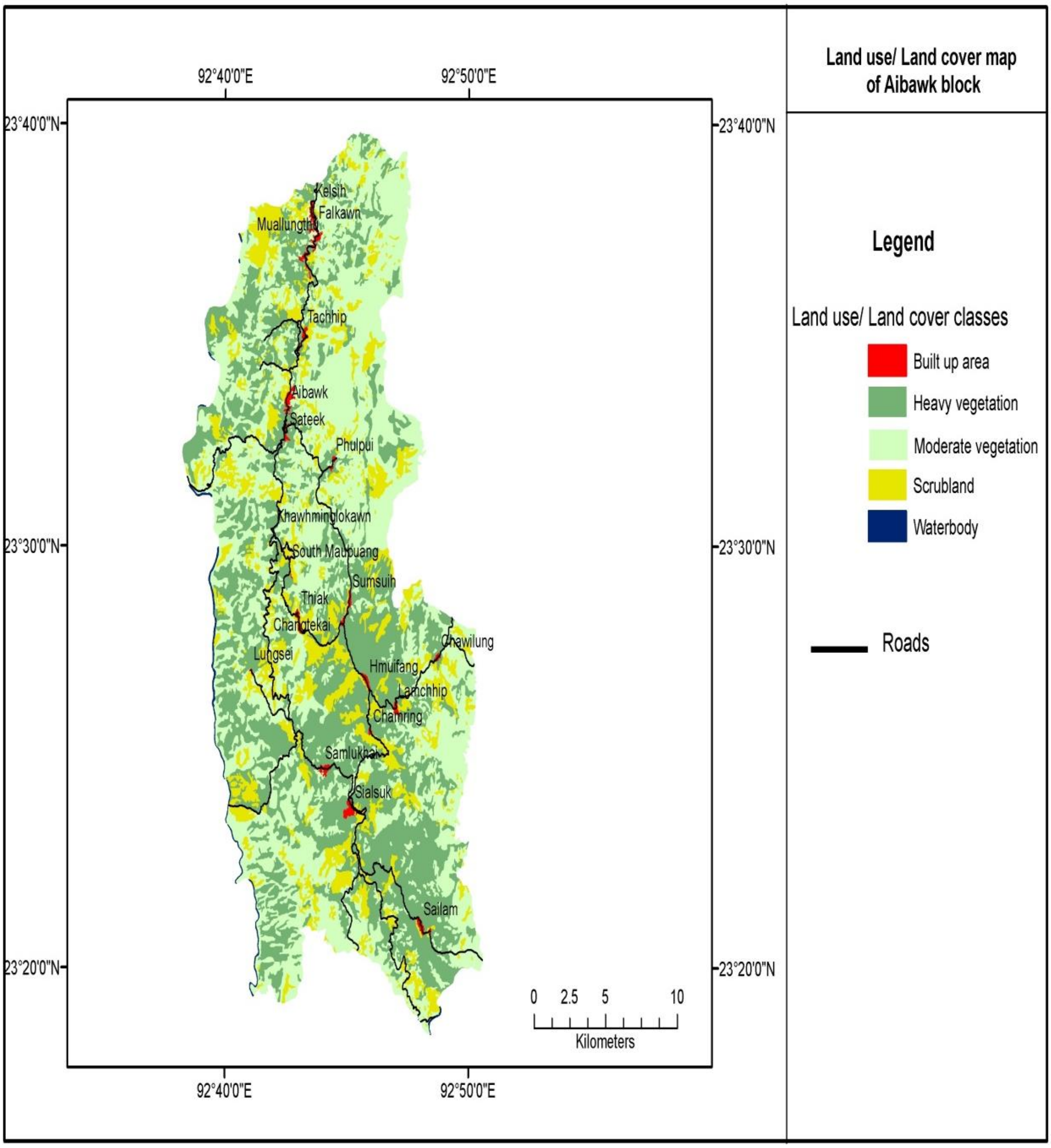


Figure 5.8: Land use and land cover types in the Aibawk Rural Development Block.

The geo-environmental factors like slope morphometry, land use/land cover, relative relief, aspect, lithology and geological structure are found to be playing significant roles in causing landslides in the study area. These five themes form the major parameters for hazard zonation and are individually divided into appropriate classes. Individual class in each parameter is carefully analyzed so as to establish their relation to landslide susceptibility within the study area. Accordingly, weightage value is assigned for each class based on their susceptibility to landslides in such a manner that less weightage represents the least influence towards landslide occurrence, and more weightage, the highest. The assignments of weightage values for the different categories within a parameter is done in accordance to their assumed or expected importance in inducing the landslides based on the prior knowledge of the experts. All the thematic layers were integrated and analyzed in a GIS environment using ARCINFO software to derive a Landslide Hazard Zonation map (Fig. 5.8). The scheme of giving weightages by National Remote Sensing Agency (NRSA, 2001) and stability rating as devised by Joyce and Evans, 1976 are combined and used in the present study as depicted in the Table 5.7.

Table 5.7: The weightage factors assigned to the various thematic layers generated for demarcating the landslide hazard zonation in the study area.

Sl. No.	Parameter	Category	Weight
1.	Lithology	Sandstone	4
		Shale	8
		Gravel, Sand & Silt	10
2.	Land Use / Land Cover	Heavy Vegetation	3
		Light Vegetation	5
		Scrubland	6
		Built-up	8
		Water body	1
3.	Slope Morphometry in degrees	0 - 15	1
		15-25	3
		25-30	4
		30-35	5
		35-40	6
		40-45	7
		45-60	8
		> 60	5

4.	Geological Structures (Faults and Lineaments)	Length of Buffer distance on either side	8
5.	Geomorphology	High	4
		Medium	3
		Low	2
6.	Relative relief	High	4
		Medium	3
		Low	2
		North	5
		North-east	4
		East	2
		South-east	6
		South	7
		South-west	8
		West	6
		North-west	3

. The Aibawk Rural Development Block area landslide inventory (Fig. 5.9) and the landslides information is also collected in the form of field photographs presented along with the name nearest settlements of about 12 villages in the study area (Table 5.8). The 16 landslides field information of selected locations are presented in the form of photographs from 1 to 16 with GPS measurements also presented in the Table 5.8 and the field photographs presented at the end of the thesis as plates from 1-8.

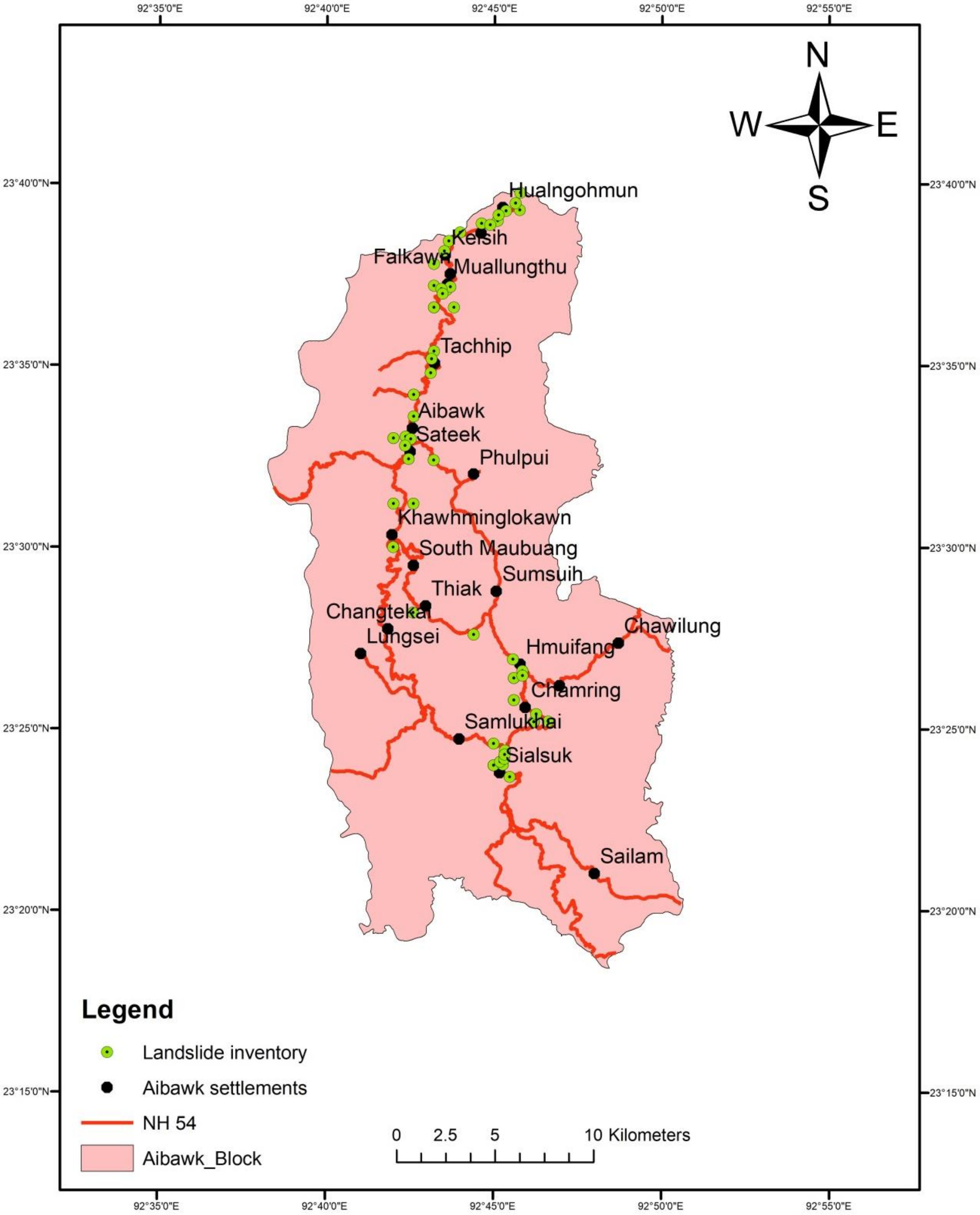


Figure 5.9: Landslides inventory locations in the study area belong to the Aibawk Rural Development Block.

Table 5.8: Field inventory of landslides with the GPS locations of different villages in the Aibawk Rural Development Block

Landslide inventory	
1. Hualngo village area (5)	**Elevation**
1) 23”39’36.6 N 92”43’41.2 E	842m
2) 23”39’33.9 N 92”43’44.4 E	835m
3) 23”39’29.8 N 92”43’45.0 E	838m
4) 23”39’25.3 N 92”43’44.8 E	829m
5) 23”39’24.0 N 92”43’39.5 E	821m
2. **Melriat village area (3)**	
1) 23”39’06.0 N 92”43’37.2 E	784m
2) 23”38’30.3 N 92”43’29.7 E	814m
3) 23”38’00.3 N 92”43’23.6 E	848m
3. **Muallungthu village area (7)**	
1) 23”36’54.5 N 92”43’03.8 E	882m
2) 23”36’30.1 N 92”43’20.4 E	863m
3) 23”36’25.0 N 92”43’30.3 E	847m
4) 23”36’14.7 N 92”43’24.9 E	826m
5) 23”36’17.3 N 92”43’23.0 E	820m
6) 23”36’19.1 N 92”43’22.0 E	815m
7) 23”35’35.6 N 92”43’01.2 E	748m
4. **Tachhip village area (3)**	
1) 23”34’32.8 N 92”42’44.2 E	848m
2) 23”34’11.1 N 92”42’26.6 E	841m
3) 23”34’07.1 N 92”42’30.1 E	828m
5. Aibawk village area (1)	
1) 23”33’44.5 N 92”42’28.2 E	813m
6. Sateek (5)	
1) 23”32’47.3 N 92”42’10.9 E	853m
2) 23”32’42.9 N 92”42’11.9 E	861m

3) 23”32’19.9 N 92”42’58.8 E	844m
4) 23”31’22.5 N 92”42’50.5 E	824m
5) 23”31’22.5 N 92”42’09.1 E	783m
7. Maubuang village area (1)	
1) 23”29’58.1 N 92”42’05.2 E	907m
8. Thiak village area (2)	
1) 23”28’28.3 N 92”42’36.4 E	996m
2) 23”27’49.9 N 92”44’11.9 E	1200m
9. Hmuifang village area (3)	
1) 23”26’21.6 N 92”45’41.0 E	1501m
2) 23”26’09.9 N 92”45’39.3 E	1487m
3) 23”25’59.9 N 92”45’39.4 E	1464m
10. Chamring village areas (4)	
1) 23”25’51.5 N 92”45’40.2 E	1451m
2) 23”25’26.2 N 92”46’10.1 E	1355m
3) 23”25’15.0 N 92”46’25.2 E	1278m
4) 23”25’05.7 N 92”46’20.4 E	1243m
11. Sialsuk village area (4)	
1) 23”25’01.3 N 92”46’16.1 E	1217m
2) 23”25’03.1 N 92”46’13.7 E	1206m
3) 23”25’08.5 N 92”46’02.9 E	1172m
4) 23”24’48.8 N 92”45’14.9 E	1066m
12. Sailam village area (3)	
1) 23”24’00.9 N 92”45’06.0 E	1189m
2) 23”24’02.1 N 92”45’09.8 E	1188m
3) 23”23’56.6 N 92”45’14.5 E	1196m

CHAPTER – VI Landslides Hazard Zonation

6.1 Types of Landslide Hazard Zonation

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

6.1.1 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. This area includes where the road cuttings with the intervention of human activity are actively undertaking. Since the Very High Hazard Zone is considered highly susceptible to landslides, it is recommended that no human induced activity be undertaken in this zone. Such areas have to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation to attain natural stability in due course of time. This area occupies 6.8 sq. km and forms around 1.3% of the total study area.

6.1.2 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. Besides, this zone comprises areas where the dip of the rocks and slope of the area, which are usually very steep (about 45 degrees or more) and in the same direction. This rendered them susceptible to slide along the slope. Significant instability may occur during and after an intense spell of rain within this zone. Several lineaments, fractured zones and fault planes also traverse the high hazard zone. Areas which experience constant erosion by streams, because of the soft nature of the lithology and loose overlying burden fall under this class. The vegetation is generally either absent or sparse. The High Hazard Zone is well distributed over the entire study area. This zone covers 291.4 sq.km of study area and it occupies 56.4 % of the hazard zone, which is half of the entire study areas.

6.1.3 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 as stable, as long as its present status is maintained. Although this zone may include areas that have steep slopes [more than 45 degree], the orientation of the rock bed, absence of overlying loose debris and the non-intervention of human activity make them less hazardous. The Moderate Hazard Zone is well distributed within the study area. Several parts of the human settlement also come under this zone. It may be noted that the seismic activity and continuous heavy rainfall can reduce the slope stability, it is recommended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, the future land use activity has to be properly planned so as to maintain its present status. This zone covers 193.8 sq.km of the study area and occupies 34.5% of total study area.

6.1.4 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 angle is generally low about 30 degrees or below. Large part of this zone prominently lies over hard and compact rock type. Flatlands and areas having gentle slope fall under this zone. This zone is mainly confined to areas where anthropogenic activities are less or absent. As far as the risk factor is concerned, no evidence of instability is observed within this zone, and mass movement is not expected unless major site changes occur. Therefore, this zone is suitable for carrying out developmental schemes. This zone spread over 193.8 sq.km and covers about 4.2% of total areas.

6.1.5 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. The dip and slope angles of the rocks are fairly low. Although the lithology may comprise of soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. This zone covers minimal area around 0.185 sq.km and cover about 3.6 %.

Table 6.1: Hazard zonation types with the percentage of areal coverage.

Hazard zonation	**Area in square**	**percentage**
Very Low	0.18	3.6
Low	24.29	4.2
Medium	193.86	34.5
High	290.42	56.4
Very High	6.82	1.3
Total area	516.38	100

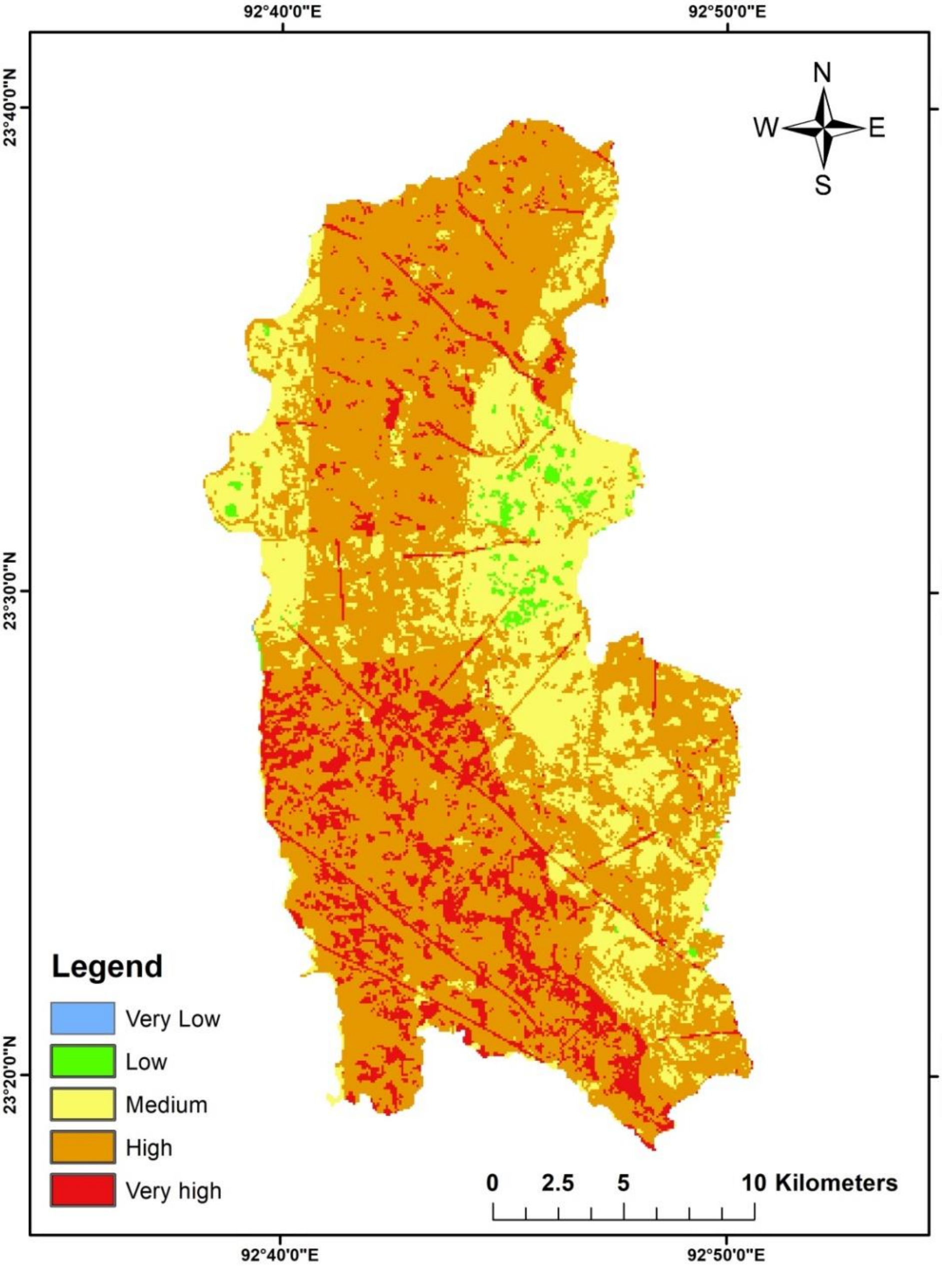


Figure 6.1: The landslide hazard zonation map of Aibawk Rural Development Block.

The information generated on landslides in the selected villages (Fig. 6.2) and the area covered is different from each village presented in the form of figures from 6.2 to 6.23.

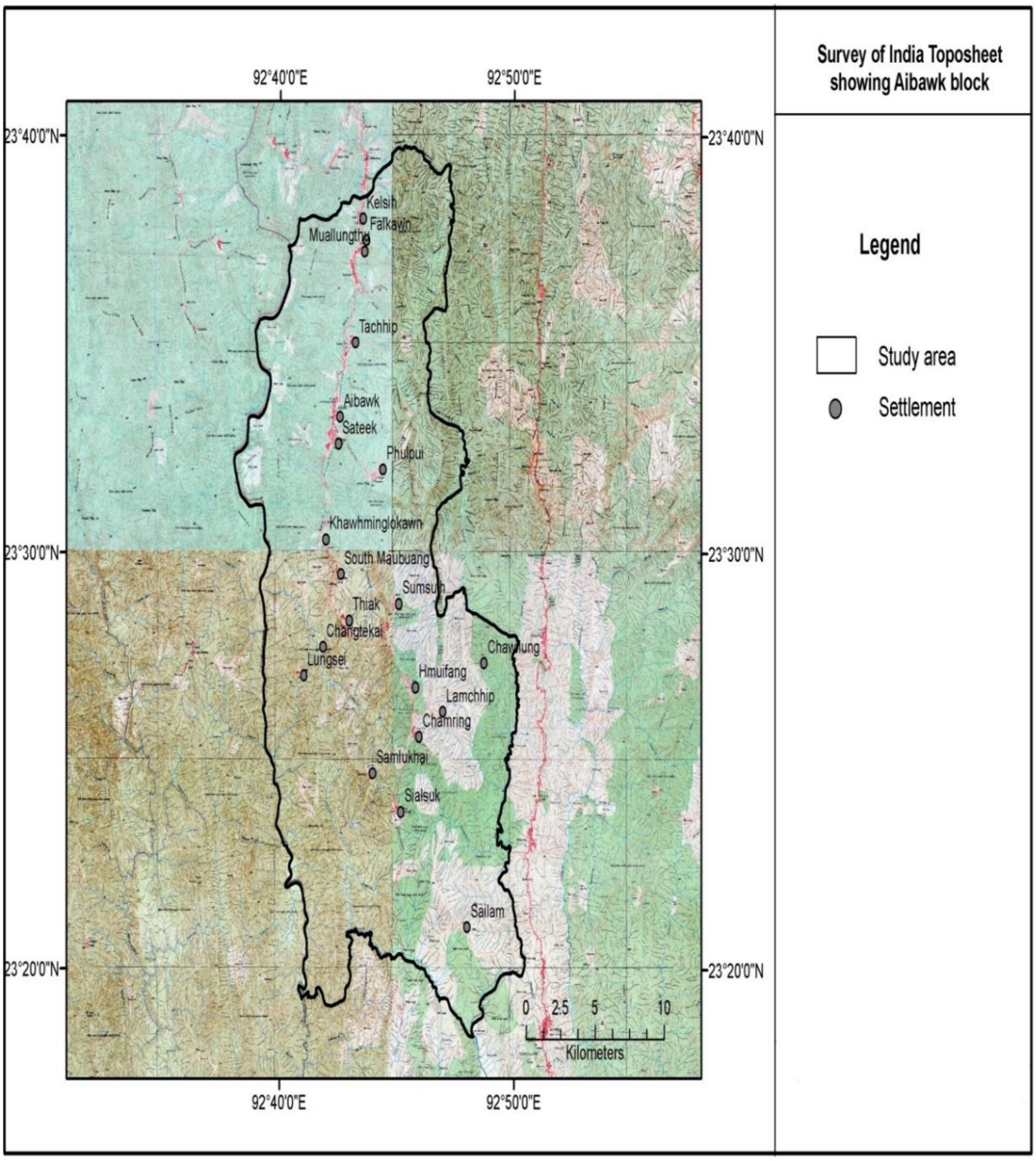


Figure 6.2: The entire Aibawk rural development block map with the selected villages for landslide data collection represented on the survey of India Toposheets.

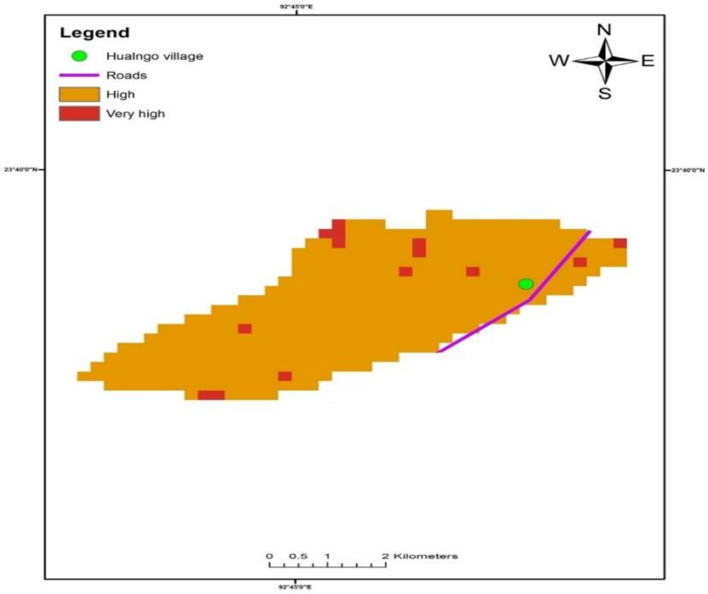


Figure 6.3: The landslide hazard zonation map of Hualngo village area.

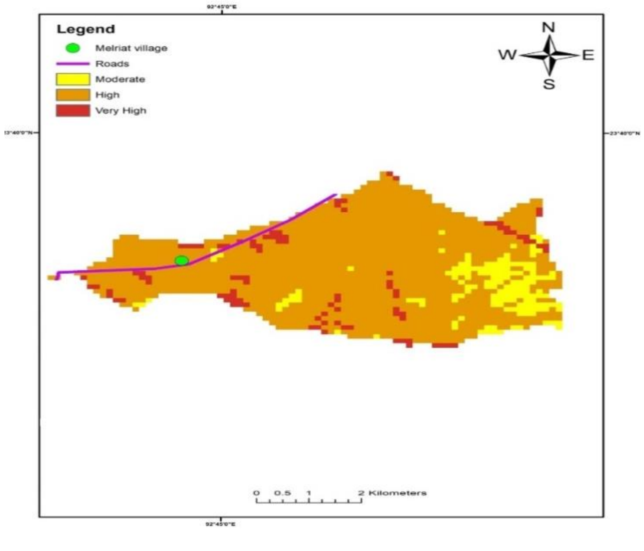


Figure 6.4: The landslide hazard zonation map of Melriat village area.

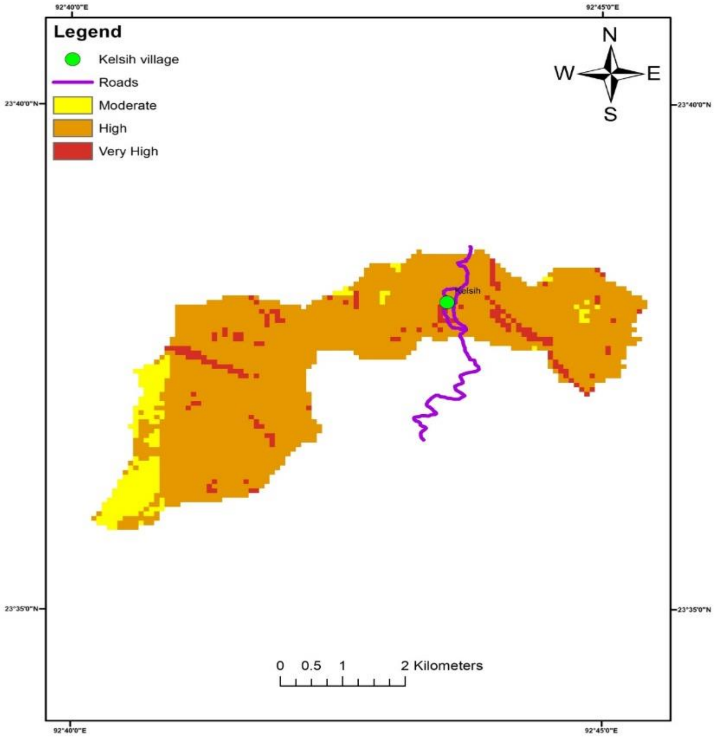


Figure 6.5: The landslide hazard zonation map of Kelsih village area.

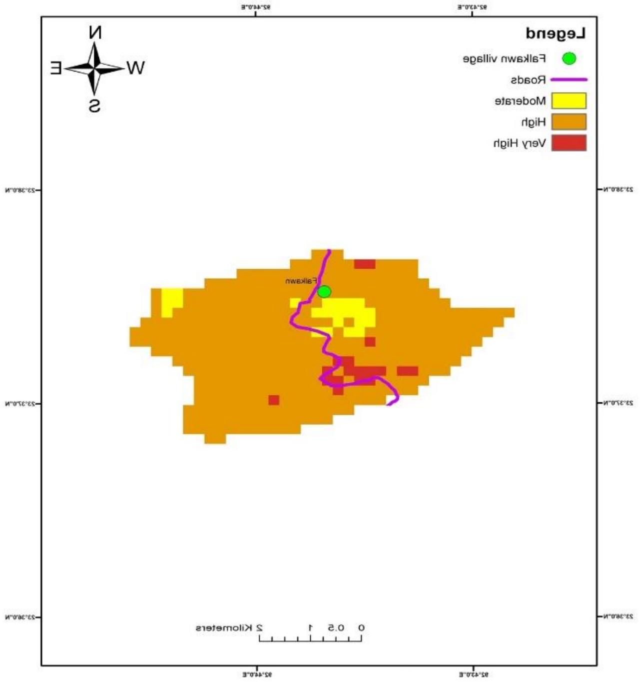


Figure 6.6: The landslide hazard zonation map of Falkawn village area.

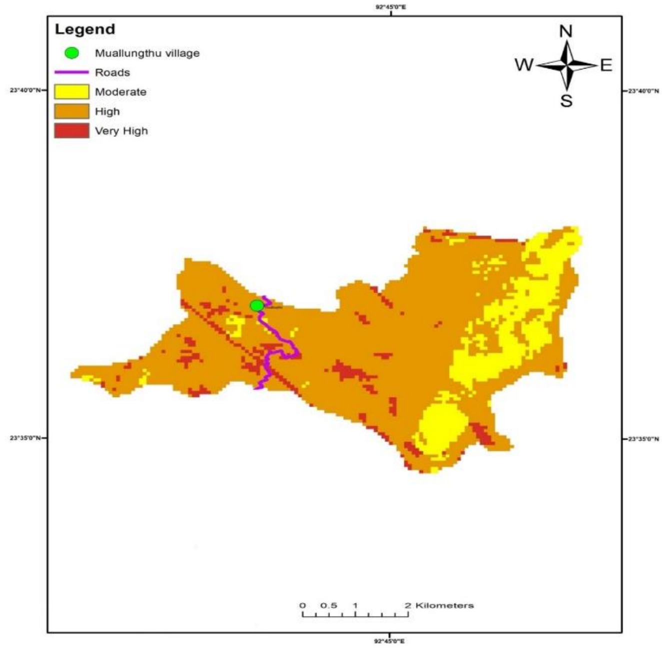


Figure 6.7: The landslide hazard zonation map of Muallungthu village area.

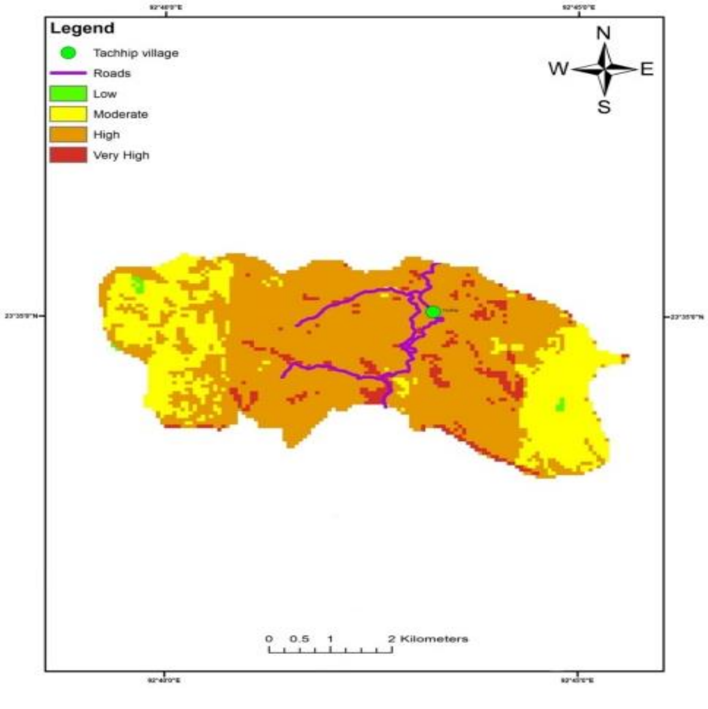


Figure 6.8: The landslide hazard zonation map of Tachhip village area.

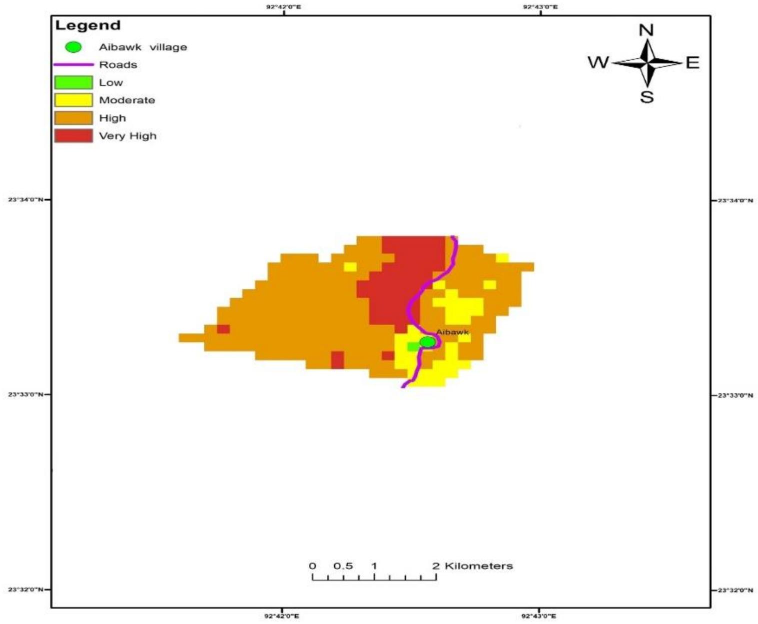


Figure 6.9: The landslide hazard zonation map of Aibawk village area.

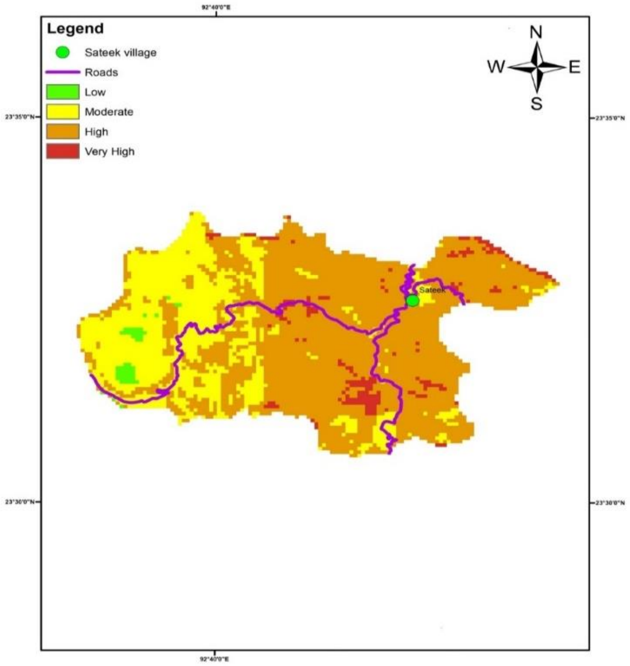


Figure 6.10: The landslide hazard zonation map of Sateek village area.

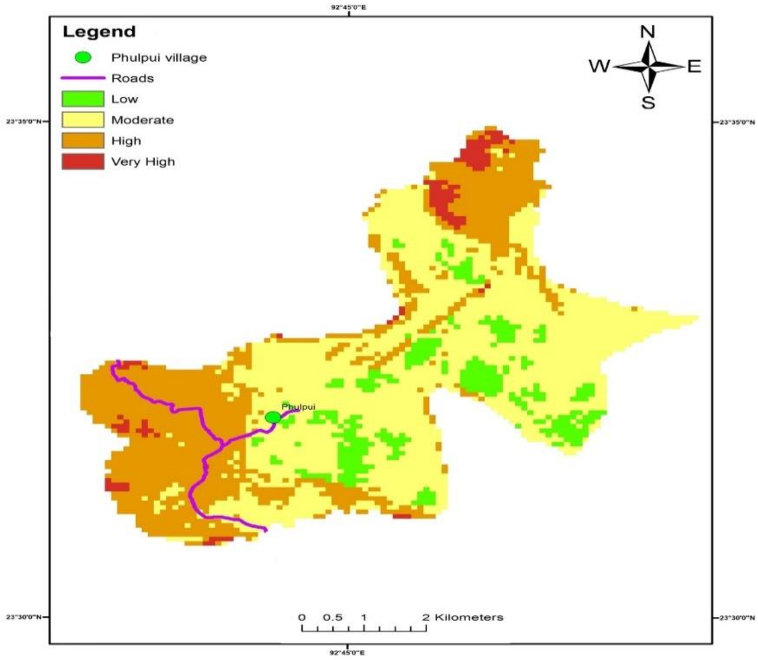


Figure 6.11: The landslide hazard zonation map of Phulpui village.

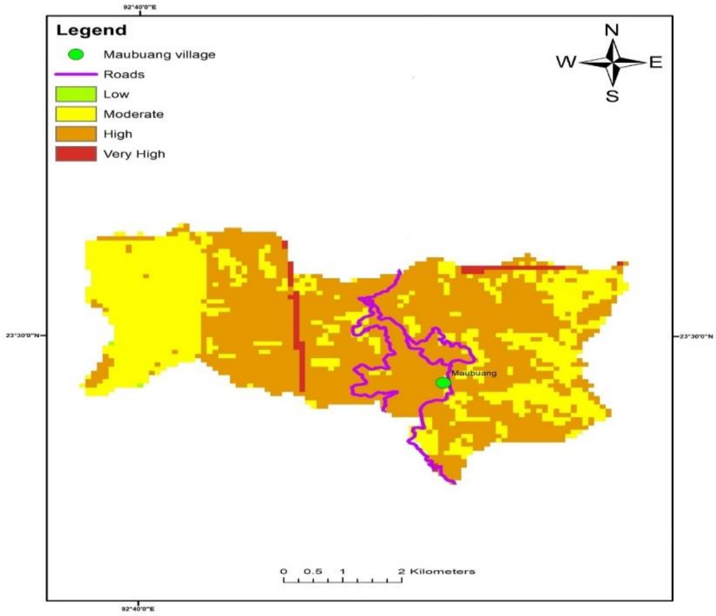


Figure 6.12: The landslide hazard zonation map of Maubuang village area.

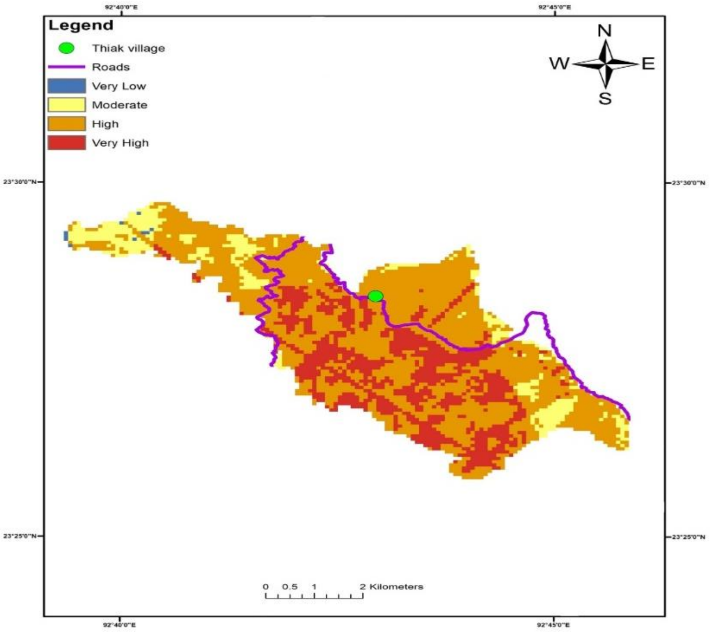


Figure 6.13: The landslide hazard zonation map of Thiak village area.

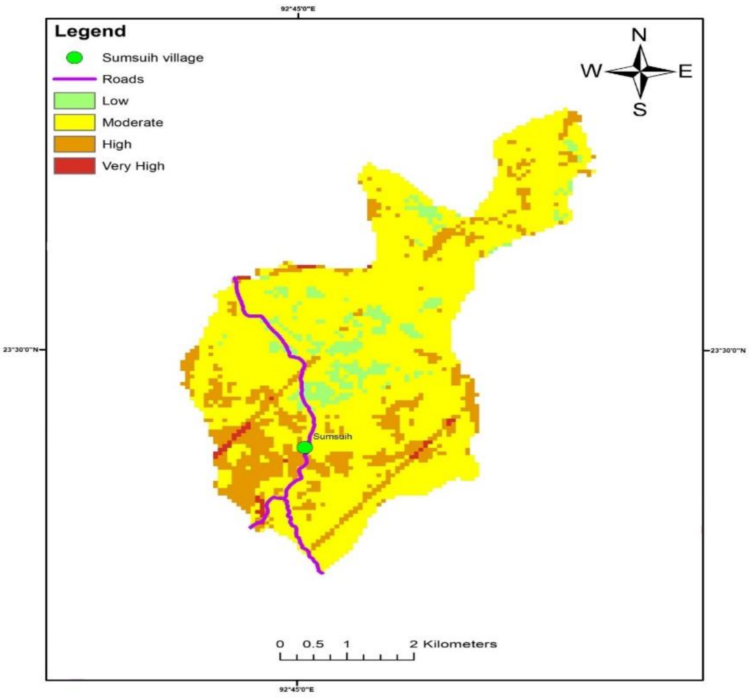


Figure 6.14: The landslide hazard zonation map of Sumsuih village area.

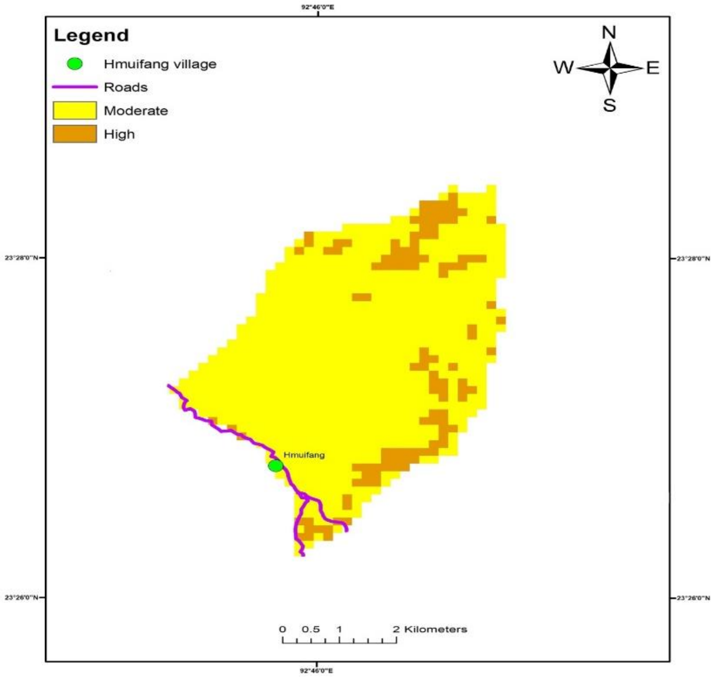


Figure 6.15: The landslide hazard zonation map of Hmuifang village area.

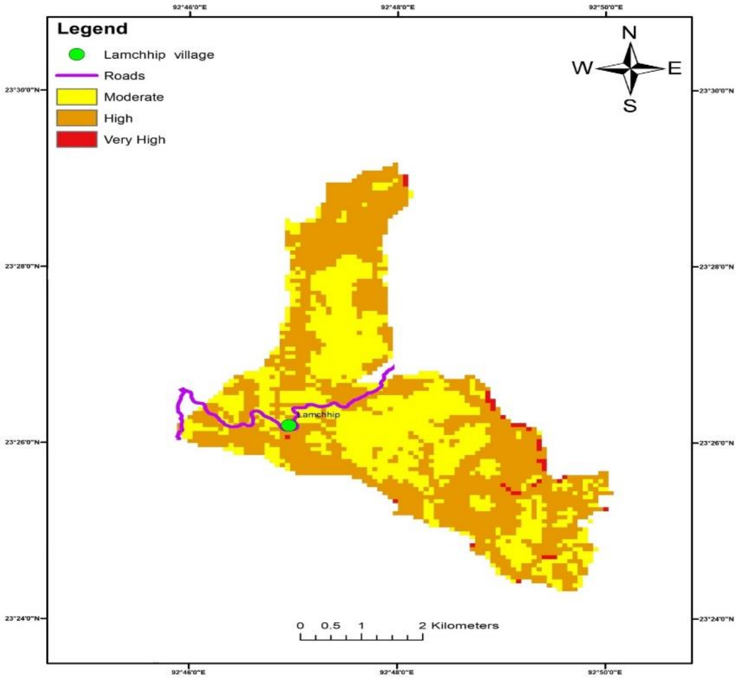


Figure 6.16: The landslide hazard zonation map of Lamchhip village area.

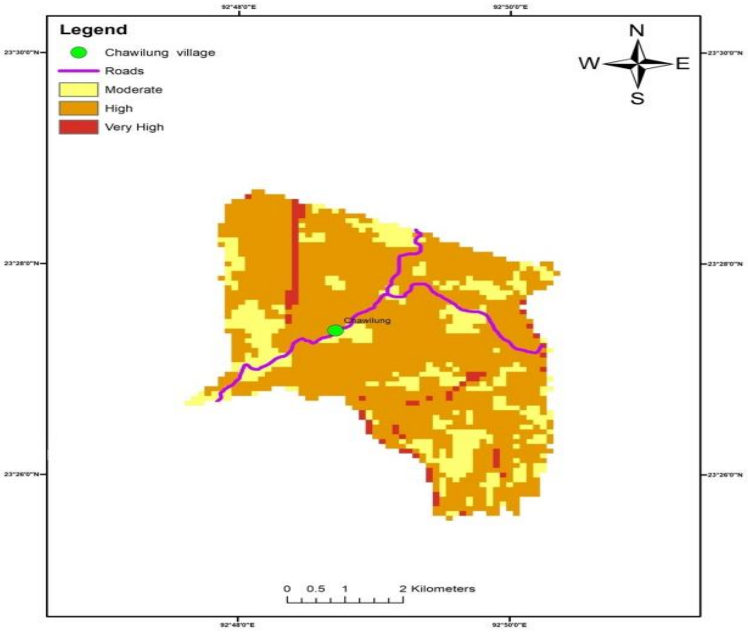


Figure 6.17: The landslide hazard zonation of Chawilung village area.

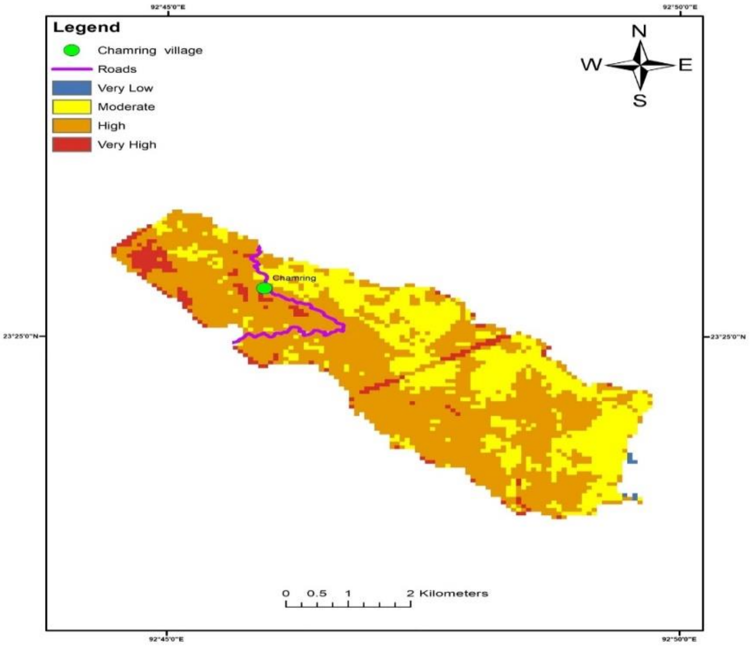


Figure 6.18: The landslide hazard zonation map of Chamring village area.

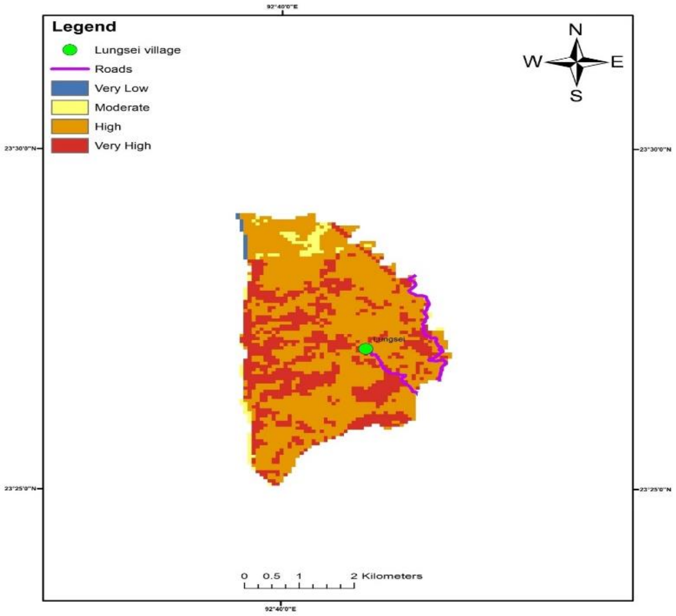


Figure 6.19: The landslide hazard zonation of Lungsei village area.

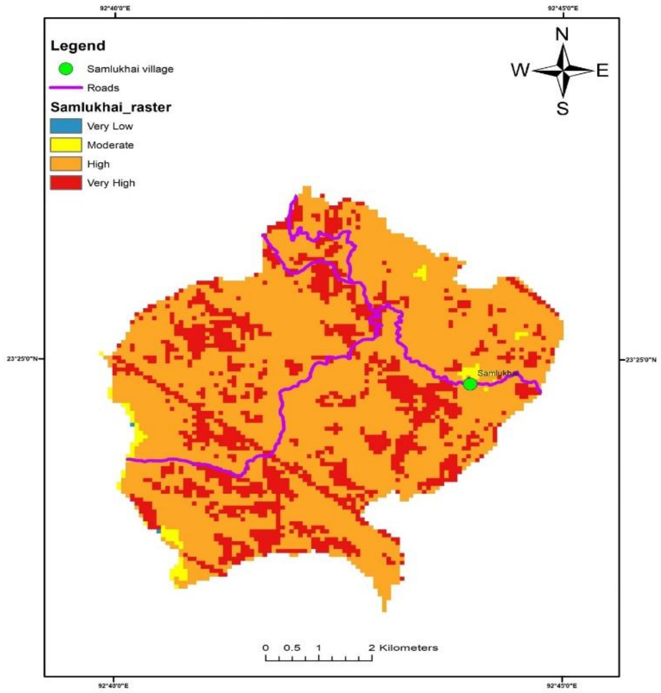


Figure 6.20: The landslide hazard zonation of Samlukhai village area.

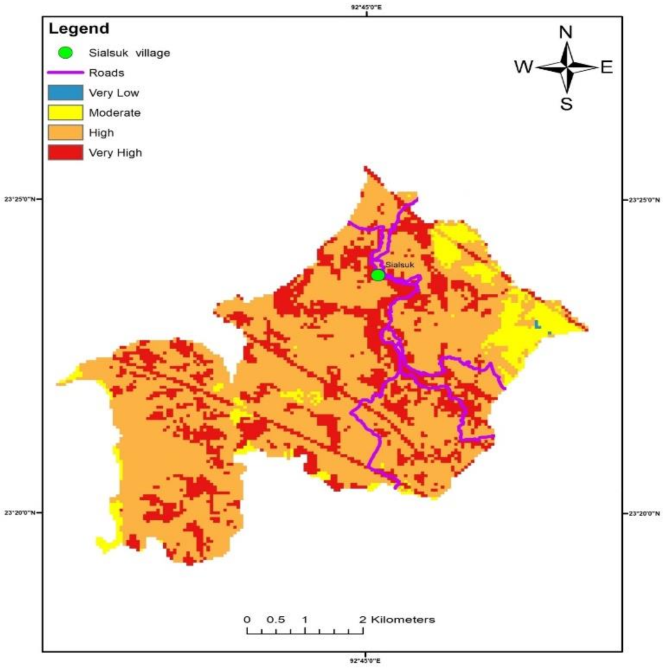


Figure 6.21: The landslide hazard zonation map of Sialsuk village area.

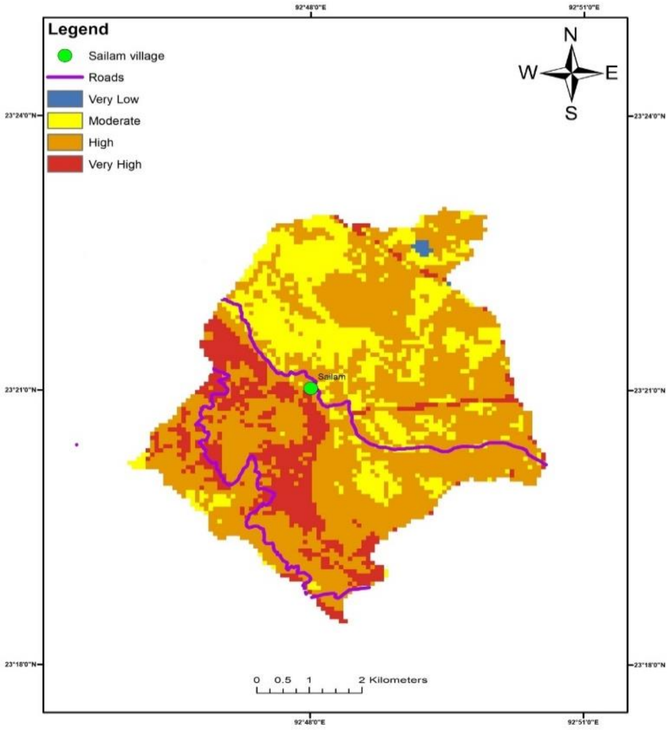


Figure 6.22: The landslide hazard zonation map of Sailam village area.

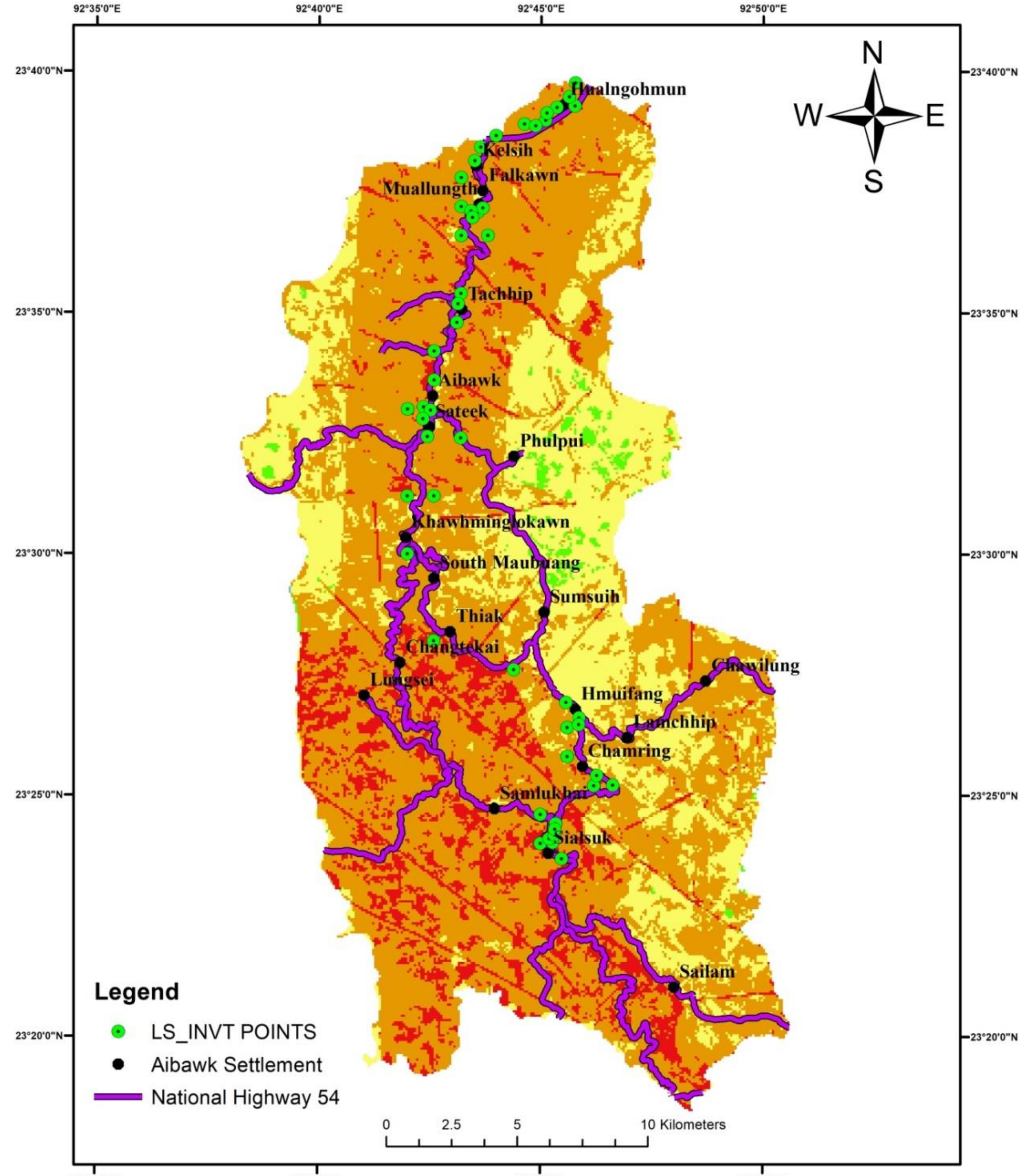


Figure 6.23: The landslide hazard location points shown in the Hazard zonation map.

6.2 Remedial measures

The benching work suggested where the straight slopes separated by near horizontal bench. It increases the stability of slopes by dividing the long slope into segments or smaller slopes connected by benches, where the proper width of bench shall be estimated by analysis of stability of slopes for a given soil. The width of bench shall not be less than 4 m, to enable the slope segments to act independently. In Benching of slopes, construction becomes easier since steeper slopes are feasible with benches. The benches shall be constructed with a V-shaped or gutter section with a longitudinal drainage grade and with suitable catch basins to carry the water down the slopes. The ditch shall be lined or paved to reduce erosion or to prevent percolation of water into pervious areas on the benches.

In High and Moderate hazard zones, afforestation scheme should be implemented. It is also recommended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, future land use activity has to be properly planned.

CHAPTER VII

SUMMARY AND CONCLUSION

The present study area lies in the central part of the state between 92^o 38.140’E to 92^o 50.738” E and 23^o 18.460’N to 23^o 39.586’N in the Aizawl district. The study area extends in parts of the Survey of India topographical map Nos. 84A/10, 84A/11, 84A/14 and 84A/15. The area is bounded in the west by the Reiek and Bunghmun Rural Development blocks in the north by the Tlangnuam and Thingsul Rural Development blocks and the eastern and southern side by the Serchhip Rural Development block.

Based on the study of distribution of landslide hazard zonation conducted for the Aibawk rural development block area, the concentration of landslides mostly along the National Highway – 52 road indicated that the natural slopes have been disturbed without any protective measures in several places, such as berms (a raised barrier separating two areas), surface and subsurface drainage, or shot-creating concrete or geo-grid planting to restrict the erosion. All these preventive measures combined with the excavated surfaces low shear strength when saturated with drainage during the rainstorms resulted in landslides. If any seismic triggering event occurs in the area, all the slopes are vulnerable to landslides. As a result, almost all the slopes in the study area should be properly inspected for landslide potential. The risk of a landslide can be reduced by implementing the proper engineering measures to make the slope more stable. The following conclusions and the suggestive preventive measures can be implemented to minimize the landslides in the Aibawk Rural Development Block.

1. Identification of High-Risk Areas: The landslide hazard zonation study successfully identified and delineated high-risk areas prone to landslides within Aibawk rural development. These areas are characterized by steep slopes, unstable soil conditions, and other contributing factors that increase the likelihood of landslides.
2. Vulnerable Settlements: The study highlighted specific settlements within Aibawk rural development 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. Urgent 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 essential information for land-use planning and regulations in Aibawk rural development. The findings can guide authorities in designating suitable land uses for high-risk areas, such as restricting construction or implementing engineering measures to stabilize slopes. Proper land-use planning can minimize the exposure of vulnerable populations and infrastructure to landslide hazards.
5. Mitigation Measures: The zonation study identified potential mitigation measures to reduce the landslide risk in Aibawk rural development. These measures may include slope stabilization techniques, installation of retaining structures, reforestation, and implementing erosion control measures. The study provides a basis for prioritizing and implementing these measures effectively.
6. Early Warning Systems: The study emphasizes the importance of establishing early warning systems specifically tailored for landslides in Aibawk rural development. Early warning systems can provide timely alerts to residents and authorities, allowing for evacuation and other necessary measures 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. Training programs, workshops, and awareness campaigns can help communities understand landslide risks, recognize warning signs, and adopt preventive measures to protect themselves and their properties.

8. Continued Monitoring and Evaluation: Landslide hazard zonation is an ongoing process that requires continuous monitoring and evaluation. Regular assessments of slope stability, changes in land use, and the effectiveness of mitigation measures should be conducted to ensure the accuracy and relevance of the zonation maps over time.

In conclusion, the landslide hazard zonation study provides crucial information for Aibawk rural development to understand and manage the risks associated with landslides. By integrating the current work findings into land-use planning, implementing mitigation measures, and enhancing community preparedness, the region can minimize the potential impact of landslides and foster a safer living environment for its residents.

Aibawk rural development area has major medical centre Zoram Medical college at Falkawn village which has also been function as major Government hospital in Mizoram. This college is well function with all medical equipment’s with specialised medical doctors. All the people in Mizoram approached this medical center due to low-cost fee and availability of highly skill doctors. The people dwell in the Aibawk rural area may be low but the people who approached Aibawk rural area is tremendously increase since the establishment of hospitalisation facility in ZMC. Beside this number of nursing colleges are also established in the Falkawn area also. Tourist spot like Hmuifang Park and Sialsuk park are the main leisurely and holi day main spot for Aizawl city people as it is not far away from Aizawl city.

Plate I

Landslide location 1. Landslide (Translational type), Chamring.

Location 2. Landslide (Translational type), Maubuang

Plate II

Location 3. Landslide (Translational type), Thiak,

Location 4. Landslide (Translational type), Thiak 2.

Plate III

Location 5. Rock fall, Midum kham.

Location 6. Landslide (Translational type) near National highway, Hualngohmun.

Plate IV

Location 7. Landslide (Translational type) near National highway, Hualngo.

Location 8. Landslide (Translational type) near National highway, Melriat.

Plate V

Location 9. Landslide (Translational type) near National highway, Tachhip.

Location 10. Landslide (Translational type) near National highway, Aibawk.

Plate VI

Location 11. Landslide (Translational type) near National highway, Maubuang.

Location 12. Landslide (Translational type) near national highway, Hmuifang.

Plate VII

Location 13. Landslide (Translational type) near national highway, Hmuifang.

Location 14. Landslide (Translational type) near national highway, Chamring.

Plate VIII

Location 15. Landslide (Translational type) near national highway, Sialsuk.

Location 16. Landslide (Debris slide) near national highway, Sialsuk.

Plate IX

Location 17. Landslide (Translational type) near national highway, Sialsuk.

Location 18. Landslide (Translational type) near national highway, Sialsuk.

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ABSTRACT

LANDSLIDE HAZARD ZONATION OF AIBAWK RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM

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

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LANDSLIDE HAZARD ZONATION OF AIBAWK RURAL DEVELOPMENT BLOCK, AIZAWL DISTRICT, MIZORAM

BY

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INTRODUCTION

The topography of Mizoram is geologically immature. There is North-South trending anticlinal ridges with steep slopes with intervening synclinal valleys. Faulting in many areas has produced steep fault scarps (GSI, 2011). Therefore, the entire area is generally prone to landslide. Landslides are closely associated with the tectonically active Himalayan regions, and can be considered as the most common natural hazards which lead to damage in the road sector and residential areas in the hilly terrains (Gurugnanam, *et al*., 2012). The vulnerability of human settlements to landslides is continuously increasing due to concentration of population and developmental activities in urban and rural areas. Thus, landslide can become a disaster when they occur in such human habitations (Chandel, *et al*., 2011). Population can be highly vulnerable to natural disasters on account of high density and locations on hill slopes (Rawat, *et al*., 2010).

There are several records of severe landslide disaster within Aizawl district during the last two decades. In 1992, massive landslide in the stone-quarry at South Hlimen village claimed the lives of 66 inhabitants and 17 houses were destroyed by this incident. In 1994, areas of Aizawl Venglai locality, Ramthar locality and Armed veng locality were sinking which caused severe damage to 65 houses. In 1995, there was a long line crack at Hunthar locality alongside Aizawl to Sairang road (National Highway 54) and about 17 houses were dismantled. In 1999, the sinking area of Hunthar locality where the same incident occurred during 1995 sunk again endangering the structures of about 12 houses and 11 families within this area were evacuated. In 2008, one house was completely washed away by landslide at Saikhamakawn causing death of two persons and injuring four persons. During the monsoon of 2011, Lengpui Airport Road was blocked by landslide causing havoc to commuters and, within Aizawl city around ten houses were dismantled and about fifteen families were evacuated. In 2012, there was a long line crack at Ramhlun Sport Complex area around ten houses were dismantled and almost sixty families were shifted. In the same year, a massive landslide at a stone-quarry near Keifang locality (Saitual town) claimed the lives of eighteen people. During the month of

May 2013, there was a massive landslide at Laipuitlang locality within Aizawl city claiming the lives of seventeen persons. More than ten persons were injured, about twelve houses and sixteen vehicles were damaged. Due to the manifold miniseries and problems it causes to the public, several attempts were made to study landslide within the state of Mizoram.

A frequently used definition of landslide is “a movement of mass of rock, earth or debris down a slope” (Cruden, 1991). They can occur on many types of terrain given the right conditions of soil, rock, moisture condition and slope. Integral to the natural process of the earth’s surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides. Classification of landslides was first formally proposed by Varnes (1978) based on types of movement and types of material. A landslide can be classified and described by two nouns; the first describes the material and the second describes the movement. The material can be rock, debris and earth or a mix. The movement can befall, topple, slide, spread and flow. Hence, a landslide can be named as rock fall (‘rock’ is the material type + ‘fall’ is the movement type), debris flow and so on. It is recommended to use a combination of one/two of these nouns to describe a landslide, though in nature, we notice a mix of material sand movements and then we are tempted to use the term ‘complex landslide’, which normally should be avoided. Zonation refers to “the division of the land into homogenous areas or domains and their ranking according to degree of actual/potential hazard caused by mass movement” (Varnes, 1984). Landslide Hazard Zonation (LHZ) is defined as the “mapping of areas with an equal probability of occurrence of landslides of a given type and magnitude within a specified period of time” (Guzzetti, *et al.*, 1999; Varnes, 1984). Landslide hazard is commonly shown on maps as areas or zones, which display the spatial distribution of landslide hazard classes. To do this, the fundamental steps are the spatial prediction of susceptible zones, estimation on the probability of magnitude of future landslide and then temporal prediction of landslide recurrence in different susceptible zones. Landslide hazard estimates in turn, are the most crucial input to risk analysis, the latter being defined as “the expected number of lives lost, persons injured and damage to property and disruption of economic activity due to a particular landslide hazard phenomenon.

Mizoram, geologically, is a part of the Tripura - Mizoram sedimentary basin of Cenozoic age (Evans, 1964). Argillaceous and arenaceous succession occurs here in alternation. Structurally, N-S trending and longitudinally plunging anticlines and synclines occur in the state (Ganju, 1975, Nandy, 1982 and Ganguly, 1983). The rock formations trend generally N-S with dips varying from 20º to 50º either towards east or west (Karunakaran, 1974). Main rock types exposed in the area are sandstone, siltstone, shale, mudstone and their admixture in various proportions and a few pockets of shell limestone, calcareous sandstone and intra-formational conglomerates. Sequentially, these are grouped into the Barail, the Surma and the Tipam Groups in the ascending order. The stratigraphic succession in the state as worked out by Karunakaran (1974) and Ganju (1975).

Presence of the Barail succession in Mizoram is rather controversial. Geologists of the Geological Survey of India like Nandy (1972, 1982) and Nandy et al. (1983) have shown the occurrence of Barail succession in the eastern part of the State around Champhai. Geologists of the Oil and Natural Gas Corporation of India, namely, Ganju (1975), Ganguly (1975), Shrivastava et al. (1979), Jokhan Ram and Venkataraman (1984), on the other hand, are of the opinion that the Barails do not occur in Mizoram and the rocks around Champhai should be included in the Surma Group only.

Objectives

The main objective of the study is to prepared Landslide Hazard Zonation map demarcating different hazard zones ranging from high to low zone in Aibawk Rural development block area. Land slide hazard zonation mapping play a vital role in development of infrastructures and town planning. The present study provides the landslide hazard zonation information, which will be helpful for the planner to sustainable development of the area. The objectives of the study are as follow:

1. To generate thematic layers of lithological, structural, slope aspect, Land use and land cover, relative relief, geomorphology by using in GIS environment with a scale of 1:25000.

2. To prepare Landslide Hazard Zonation map.

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

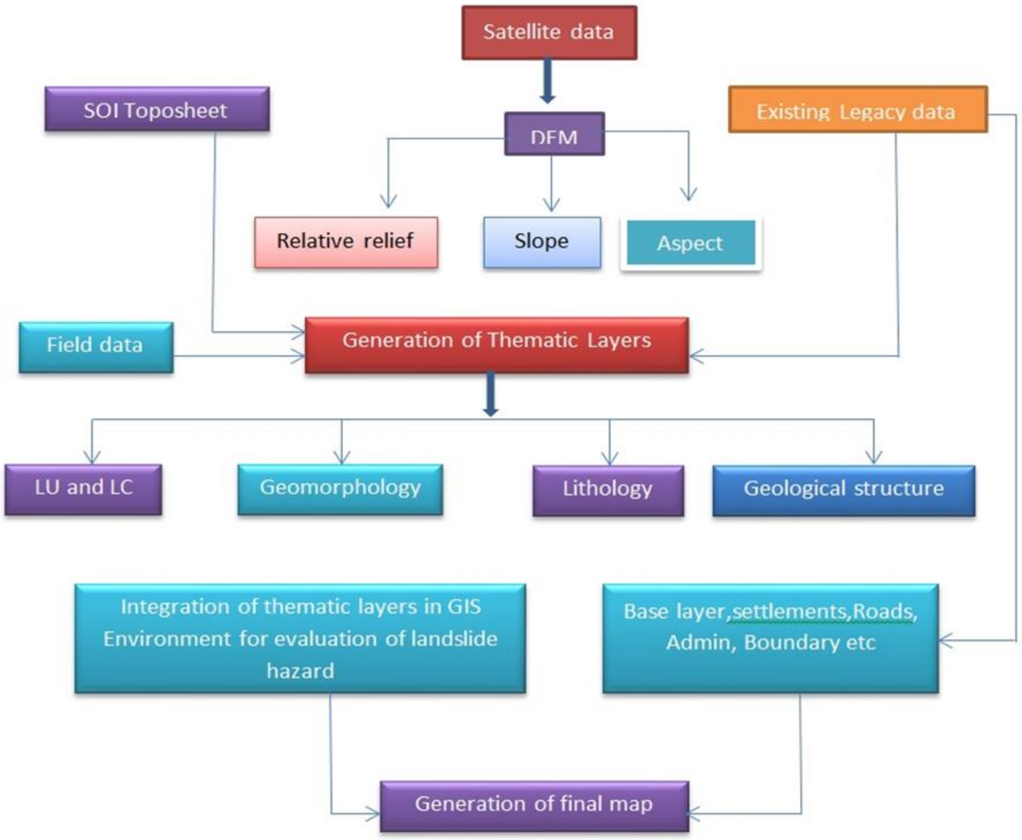
Location of study area

The study area lies in the central part of the state between 92o 38.140’E to 92o 50.738” E and 23o 18.460’N to 23o 39.586’N in Aizawl district and falls under Survey of India topographical map No. 84A/10, 84A/11, 84A/14 and 84A/15. The area is bounded in the west by Reiek and Bunghmun Rural Development blocks (Fig. 1.4), in the north by Tlangnuam and Thingsul RD blocks and the eastern and southern side by Serchhip RD block.

Methodology and material

The present work utilizes the standard procedures of Satellite Imagery interpretation and GIS techniques for preparing the thematic information ultimately transform in to the different form of maps.

The methodology is basically a systematic procedure evolved to assess the landslide susceptibility of the study area using remote sensing data and GIS techniques in conjunction with limited field work. Various steps involved in the methodology are furnished as shown in the form of a flow chart in the figure given below: -



The methodology can be divided into two main parts. The first part deals preparation of individual thematic maps i.e. lithology, geomorphology, geological structures and base map details based on the visual interpretation of satellite data and Survey of India Topographic map in conjunction with limited field / existing data.

The second part deals with the derivation of landslide hazard map by integrating the thematic data. The methodology was adopted from Landslide hazard zonation project carried out by National Remote Sensing Agency in 2001.

Resultant output from this will be in vector format, comprising of point, line and polygon features, which supports complex GIS analysis.

The landslide susceptibility assessment offers crucial information for determining the risk of landslides. Landslide inventories and susceptibility maps are important in landslide-prone areas throughout the country (Spiker and Gori, 2000). The aim of the landslide susceptibility map is to identify areas that could be impacted by landslides in the future due to natural or human-caused factors. These maps must be adequately accurate to help local mitigative measures.

Thematic mapping: All the data pertaining to the factors controlling the occurrence of landslide are mapped in the form of thematic layers. All the relevant elements for understanding the ground conditions are systematically studied and considered in an orderly manner for mapping and even missing of one element may also leads to erroneous conclusions.

i) Base map layer: It consists of four categories of information. They are –

a) Administrative

b) Settlements

c) Road network

d) Drainage

The landslide susceptibility mapping approaches can be classified into three categories in general namely qualitative, semi quantitative and quantitative (Lee and Jones, 2004). The qualitative approach is a subject-oriented method that works well over broad areas, while the quantitative method is an object-oriented method that looks for a connection between environmental variables and previous landslide occurrences. The researchers who have developed several approaches based on those techniques, such as heuristic approach by Ruff and Czurda (2007), statistical approach by Carara et al (1991), deterministic by Soeters and Westen (1996) and probabilistic approach by Guzzeti et al (2005).

Heuristic approach

The heuristic approach is based on opinion of geomorphology experts. The key input for deciding landslide hazard zonation is the landslide inventory map, which is followed by environmental factors, and then the experts determine the weightage value. Heuristic approach takes into account a hierarchical level and different approaches for determining weightage factors. Next, the hierarchical heuristic model becomes a part of decision support system (DSS) which aims for spatial decisions

(Castellanos and Van Westen, 2003). Generally, this approach can be divided into two parts, direct mapping analysis and qualitative map combination. In the direct mapping analysis, the geomorphologists determine the susceptibility in the field directly, which is based on their field-based experience. In the later analysis, the experts use their knowledge to determine the weightage values for each class in each parameter. The main problem of this approach is in determining the exactly weightage value because this approach is mainly subject oriented method.

Data acquired

The accessible data such as literature on landslides and the meteorological data are collected from different sources during the pre-field work. The MIRSAC (Mizoram Remote Sensing Application Center) data was used for interpreting the satellite imagery of the study area. The satellite imagery is geo-referenced and the base maps for different themes generated from the Survey of India (SoI) toposheets on 1:50,000 scale. The image processing software is used to perform the image classification and the pre-field analysis by using ArcGIS.

Preparation of the following thematic maps which was generated on scale 1:50000.

i) Geomorphology and Lineament map

ii) Slope, Aspect Map and Contour Map

iii) Land use/land cover map

iv) Drainage map

v) Lithology and structural map

The collection of landslide inventory data for landslide hazard zonation is from spatial and temporal landslide information from archives, temporal satellite imagery interpretation and the data transformed either in to grid cells, terrain units, slope units or in to topographic units (Reichenbach et al., 2018; Guzzetti et al., 1999). The main goal of the combining various data sources is to get more reasonable results when evaluating a variety of environmental issues (Archana and Kausik, 2013). The total of eight thematic maps generated based on the satellite imagery interpretation and followed by field confirmation of the interpreted results.

Pre- field work

During the pre-field work available information like literature, maps, socio-economic data, meteorological data are collected from various sources. Satellite imageries of the study area are also acquired. The satellite imagery is registered with respect to Survey of India toposheets, and the base maps for different themes are generated. The digital classification the data and the pre-field interpretation are carried out by using the Geographical Information System software through Arc Info platform. The various thematic layers such as lithology, geomorphology, drainage, contour map, slope map, land use and land cover prepared based on the interpretation of satellite data with the available collateral data are also used in the generation of preliminary/Pre-field maps utilized for field verification.

Field work

The field work or ground truth collection is a very important aspect after the interpretation of satellite imagery for various thematic maps generation. The available ground information is collected during the field work and the pre-field interpreted maps also verified and corrected based on the ground truth verification. The hand-held GPS is used for mapping the locational information of the different selected features interested in the field. The field verification or ground truth collection is an essential part of the interpreted satellite imagery. The important ground truth data was collected during the field visit and the doubtful features mentioned while interpreting the satellite image through pre-field maps preparation were conformed in the field work. All the landslide sites within the study area were recorded with hand held GPS.

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 of landslide disaster 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.

Slope Morphometry

In the slope stability study, the slope angle is regarded one of the most significant parameters (Lee and Min, 2001). 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 Arc GIS 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., 1999).

Slope aspect

The slope aspect map is being created for the present research 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.

Morphometric 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 plant kinds and rainfall, may influence 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 on topographic sheets from the Survey of India and satellite imagery. For representational purposes, the map has been scaled down to 1:25,000 scale. The proximity of faults was created using 50-m buffer zone. For this research, a lithological map of the study region 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 programmed.

Result and discussion

Land slide Hazard Zonation and risk assessment

The Task force on landslide Hazard Zonation set up by the Ministry of mines, Govt. of India suggested that the scales of landslide hazard zonation maps should be agreed to bear in mind the purpose for which they are going to be used. The task force defined the three levels of scales for which the purpose of the landslide hazard zonation maps further utilized for the sustainable mitigative measures. The scale on the map 1cm represents 25,000 cm in the ground. Further, the task force has defined the scales which depend on the areal coverage.

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 selection of conditioning factors is often referred to as the selection of attributes also important. In a GIS environment defined by various thematic layers namely geological, morphometry, hydrological and environmental parameters, and by synthetic parameters derived from discretizing, reclassifying or performing statistical operations on inputs.

After the field verification, the pre-field maps are finalized by making necessary corrections and modifications. Various data collected from the field are studied and analyzed. After finalization of the primary layers, the derived layers are prepared by using several primary layers. Area calculation is also done to obtain spatial coverage. Finally, report consisting of the description and landslide hazard map and also the action plan for mitigation of landslide disaster of the study area is prepared.

The majority of the landslides observed and checked in the field were shallow translational debris/rock slides with a slip plane depth of approximately between 2-4 meters. Since the road provides a horizontal foundation for debris accumulation, most landslides occur on the road's upslope and have a very short or no run out distance. No landslide was seen below highway during field work. The present area has face constant rock fall throughout the year due to construction of national high way. The rock falls those are presented in the study area where the shale and sandstone inter-bedded localities. This type of rock formation is prone to weathering and erosion. As shale is weather more easily than sandstone, this may lead to wedging and which fail slowly and led to rock fall. The rock fall area belongs to vertical rock wall and this area also undergone regular rock blasting during widening of the national highway. The blasting effect may have caused fractures and weakening of joint sets present in the area. Hence, rock fall occur throughout the year. Landslide along major highway is a common phenomenon during monsoon period in the study area. Rainfall and anthropogenic activities are the key triggering factors of landslides in the study region. The number of slope failures triggered by rainfall combined with the inherent causative factors is extremely high during the monsoon months. Thirteen landslides were identified during field work and landslides occurred mostly along the highway.

Results derived from various thematic layers

The generated various thematic layers of the study area have been analyzed and interpreted, the statistics and the maps showing different classes within each factor affecting landslides were generated using satellite imagery by ArcGIS software.

Geological factors

Lithology

Landslide initiation is influenced by the geological rock formation. The rock unit features of any hill region control slope failure. Because different lithological rocks structures have varying susceptibilities to active geomorphic processes, lithological structure plays an important role in landslide hazard zonation (Pradhan et al. 2007, 2009). The lithology is one of the controlling parameters in slope stability since each class of materials has different shear strength and permeability characteristics (Yalcin and Bulut, 2007). Lithology plays a major role in the slope movements such as rock fall influenced by rock hardness, fractures and the weathering of rocks. The lithology reflects the engineering properties of rocks in the region. The adhesion properties and internal friction angle of the engineering properties of lithology are a lot of impact.

Different rock types have varied composition and structure which contribute to the strength of the slope material in a positive or negative way. The stronger rock units give more resistance to the driving forces as compared to the softer/ weaker rocks.

The resistance of rocks to the weathering and erosion process is the important aspect in controlling the slope stability. The study area includes the Tertiary formations of Bhuban and Bokabil that belongs to the Surma Group, which are made up of primarily arenaceous and argillaceous rocks. Four litho-units have been established for the study area purely based on the exposed rock types of the area. These are referred to as gravel-silts and clays/shales belong to the Bokabil formation, sandstones referred as the Upper Bhuban formation, and the shales belong to the Middle Bhuban formation. The unconsolidated material units have a higher risk of slope collapse than other units; they are assigned the highest weightage value. Siltstone and shale lithological formations are more prone to landslides than hard and compact sandstone strata.

Based on the analysis of Lithological data shale and sandstone alterations forms majority of the study area with 307.sq.km (60%) shale and sandstones 191 sq.km (37%), pockets of gravel, sand and silt covering a small area of 18 sq. km (3%).

Geological structure

The tectonic breakdowns such as faults, thrusts, and shear zones are lithological structures that play a significant role in the occurrence of landslides. Because these fractures reduce rock strength, they are considered susceptible landslide initiating sites (Pradhan and Youssef, 2009). 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 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, fractures, and junctions (Kanungo, et al., 1995). The most significant factors for Landslide Hazard Zonation are 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. The occurrence of landslides is influenced by the geological formations with the geological structures. The discontinuity connected with the insitu- rocks across hill slopes including bedding planes, joints, foliations, faults and fractures. Slope stability is influenced more by structural discontinuity in relation to slope inclination. The correlation of slope direction and discontinuity parallelism, discontinuity of dip and slope dip direction and also discontinuity of dip. The rocks exposed in the region are pierced by a number of faults and fractures of variable size and length (MIRSAC, 2006). Areas close to fault zones and other geological features are thought to be more susceptible to landslides.

Geomorphology

The study area consists of structural hill ranges that are highly dissected, undulating, and moderately sloping. Some of the hillocks are highly dissected, with sharp ridges and steep slopes, while others are gentle and low dissected. This shows that the topography is still in its infancy. A small number of flat plains can be found largely along streams and between spurs. The entire area is divided into four geomorphological categories: high structural hill, medium structural hill, low structural hill, and valley fill. Landslides are more likely to occur in high-elevation locations than in low-elevation areas. The study area is divided into five types of geomorphic classes. Flood plain cover 1%, high dissected area occupies 5%, medium dissected area covers 65%. Low dissected and valley hill cover 28% and 1% respectively.

Relative relief

The study area possesses high relative, medium or local relief. The higher values indicate rapid rise in altitude and presence of faults, lower relief signifies mature topography. Relative relief is an important factor in landslide hazard zonation. It plays a decisive role in the vulnerability of settlements, transport network and land (Chandel, et al, 2011). The highest point within the study area has an elevation of 855m from the mean sea level. The whole area was divided into High, Moderate and Low classes in terms of relative relief with 1601m to lowest 400m from sea level. High elevated areas are more susceptible to landslide than areas with lower elevation (Lee, et al., 2004).

Slope morphometry

The slope map is prepared (Fig. 5.5) based on the generated STRM DEM image in the GIS domain for the landslide hazard study in the area. The slope map is categorized into 7 slope category classes. The slope represented in the study area is in degrees and categorized into seven classes as 1. 0-150; 2. 15-250; 3. 25-300; 4. 30-400; 5. 35-400; 6. 40-450; and 7. > 450.

Slope Aspect Map

Another important event conditioning characteristic is slopes aspect, which has been studied by a number of scholars (Nagarajan et al. 1998; Yalcin et al. 2011; Pourghasemi et al. 2013; Ghosh et al. 2014). The slope aspect refers to slope orientation which is generally expressed in terms of degree from 00-3600. The slope aspect map of the study area is prepared based on the interpretation of satellite imagery (Fig. 5.6). It is considered as an important factor in landslide studies as it controls slope exposures expose to sunlight, wind direction, rainfall (degree of saturation) and discontinuity conditions (Komac, 2006). Various hydro-meteorological phenomena, such as the quantity of sunlight, precipitation, and the area's topography, influence landslide initiation (Pourghasemi, et al. 2013). The amount of rainfall received on the slope's hillside is related to the slope's alteration capacity, which can be influenced by a variety of factors including the slope's topography, permeability of the rock structure, porosity, moisture retention, organic ingredients, land use, and climatic season (Pourghasemi, et al. 2013). The south facing hill slope of the Himalayan Mountain landscape receives the most rainfall, which is considerably higher than the north facing slope (Ghosh, et al. 2014).

Topographic map

A topographic map is a map that uses elevation contour lines to depict the form of the Earth's surface features. Elevation contours are fictitious lines that connect locations on the land's surface that have the same elevation above or below a reference surface, which is usually mean sea level. Contours may be used to represent the height and form of mountains, the depths of valleys, and the steepness of slopes.

On topographic 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. Hydrography includes lakes, rivers, streams, marshes, rapids, and falls. The most prevalent kind of vegetation is wooded regions. The digital elevation model of the study area is prepared based on the SRTM data of 30m interval.

Land use and land cover

Land-use change has been recognized throughout the world as one of the most important factors influencing the occurrence of rainfall-triggered landslides. Changes in land use/cover resulted from man-made activities such as deforestation, overgrazing, intensive farming and cultivation on steep slope can initiate slope instability (Glade, 2003). Land use land-cover (LULC) pattern is one of the important parameters in controlling the slope stability. Vegetation has major role to resist slope movements, particularly for failure of shallow depth slip or rupture surfaces. Vegetation has a major contribution to resist slope movements. Vegetation having a well-spread network of root systems increases shearing resistance of the slope material. This is due to the natural anchoring of slope materials. In addition to this, it reduces the action of erosion and adds the stability of the slope. In another way, barren or sparsely vegetated slopes are usually exposed to erosion and thus it has the effect of increasing slope instability. Land use has a big impact on landslide initiation. The land cover also affects the slope stability of the area. Slope instabilities can be avoided by long-term vegetative cover. A well-distributed root system increases the shearing resistance of the slope material due to natural anchoring. Furthermore, because the plant's root network takes water from the soil mass to perform metabolic functions such as photosynthesis and transpiration, the moisture content of slope material is kept under control (even during natural precipitation cycles). The hill slopes in the research region area are made up of overburden material like colluvium and/or highly worn mantle of shallow thickness, yet dense vegetation or grass cover might reduce the influence of physical weathering and subsequent erosion, boosting the slopes' stability. Slopes that are barren or sparsely vegetated, on the other hand, are more prone to weathering and erosion, making them more likely to fail. When determining landslide susceptibility mapping, this is one of the most significant aspects to consider. Plant coverings, for example, strengthen the soil by supporting the roots. It offers a lot of potential for reducing slope failure rates (Begueria, 2006). The land use/land cover pattern, which is one of the most important factors affecting slope stability, controls the rate of weathering and erosion (Anbalagan, et al., 2008). In comparison to all other groups, built-up regions were shown to be the most sensitive to landslides (Pandey et al., 2008), while dense vegetation areas were found to be less prone to landslides (Pandey et al., 2008). The study area 0.537% is covered by built up area, 36.251% is occupied by heavy vegetation and moderate vegetation also covers 47.039% and also the largest area by percentage in the area in land use and land cover categories). The Scrubland and water body also cover 16.17% and 0.0014%, respectively in the study area.

The geo-environmental factors like slope morphometry, land use/land cover, relative relief, aspect, lithology and geological structure are found to be playing significant roles in causing landslides in the study area. These five themes form the major parameters for hazard zonation and are individually divided into appropriate classes. Individual class in each parameter is carefully analyzed so as to establish their relation to landslide susceptibility within the study area. Accordingly, weightage value is assigned for each class based on their susceptibility to landslides in such a manner that less weightage represents the least influence towards landslide occurrence, and more weightage, the highest. The assignments of weightage values for the different categories within a parameter is done in accordance to their assumed or expected importance in inducing the landslides based on the prior knowledge of the experts. All the thematic layers were integrated and analyzed in a GIS environment using ARCINFO software to derive a Landslide Hazard Zonation map. The scheme of giving weightages by National Remote Sensing Agency (NRSA, 2001) and stability rating as devised by Joyce and Evans, 1976 are combined and used in the present study.

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

Sl**. No.**	**Parameter**	**Category**	**Weight**
1.	Lithology	Sandstone	4
		Shale	8
		Sandstone	3
		Gravel, Sand & Silt	10
2.	Land Use / Land Cover	Heavy Vegetation	3
		Light Vegetation	5
		Scrubland	6
		Built-up	8
		Water body	1
3.	Slope Morphometry in degrees	0 - 15	1
		15-25	3
		25-30	4
		30-35	5

		35-40	6
		40-45	7
		45-60	8
		> 60	5
4.	Geological Structures (Faults and Lineaments)	Length of Buffer distance on either side	8
5.	Geomorphology	High	4
		Medium	3
		Low	2
6.	Relative relief	High	4
		Medium	3
		Low	2
		North	5
		North-east	4
		East	2
		South-east	6
		South	7
		South-west	8
		West	6
		North-west	3

Landslides Hazard Zonation

Types of Landslide Hazard Zonation

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

6.1.1 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. This area includes where the road cuttings with the intervention of human activity are actively undertaking. Since the Very High Hazard Zone is considered highly susceptible to landslides, it is recommended that no human induced activity be undertaken in this zone. Such areas have to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation to attain natural stability in due course of time. This area occupies 6.8 sq. km and forms around 1.3% of the total study area.

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. Besides, this zone comprises areas where the dip of the rocks and slope of the area, which are usually very steep (about 45 degrees or more) and in the same direction. This rendered them susceptible to slide along the slope. Significant instability may occur during and after an intense spell of rain within this zone. Several lineaments, fractured zones and fault planes also traverse the high hazard zone. Areas which experience constant erosion by streams, because of the soft nature of the lithology and loose overlying burden fall under this class. The vegetation is generally either absent or sparse. The High Hazard Zone is well distributed over the entire study area. This zone covers 291.4 sq.km of study area and it occupies 56.4 % of the hazard zone, which is half of the entire study areas.

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 as stable, as long as its present status is maintained. Although this zone may include areas that have steep slopes [more than 45 degrees], the orientation of the rock bed, absence of overlying loose debris and the non-intervention of human activity make them less hazardous. The Moderate Hazard Zone is well distributed within the study area. Several parts of the human settlement also come under this zone. It may be noted that the seismic activity and continuous heavy rainfall can reduce the slope stability, it is recommended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, the future land use activity has to be properly planned so as to maintain its present status. This zone covers 193.8 sq.km of the study area and occupies 34.5% of total study area.

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 angle is generally low about 30 degrees or below. Large part of this zone prominently lies over hard and compact rock type. Flatlands and areas having gentle slope fall under this zone. This zone is mainly confined to areas where anthropogenic activities are less or absent. As far as the risk factor is concerned, no evidence of instability is observed within this zone, and mass movement is not expected unless major site changes occur. Therefore, this zone is suitable for carrying out developmental schemes. This zone spread over 193.8 sq.km and covers about 4.2% of total areas.

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. The dip and slope angles of the rocks are fairly low. Although the lithology may comprise of soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. This zone covers minimal area around 0.185 sq.km and cover about 3.6 %.

Remedial measures

The benching work suggested where the straight slopes separated by near horizontal bench. It increases the stability of slopes by dividing the long slope into segments or smaller slopes connected by benches, where the proper width of bench shall be estimated by analysis of stability of slopes for a given soil. The width of bench shall not be less than 4 m, to enable the slope segments to act independently. In Benching of slopes, construction becomes easier since steeper slopes are feasible with benches. The benches shall be constructed with a V-shaped or gutter section with a longitudinal drainage grade and with suitable catch basins to carry the water down the slopes. The ditch shall be lined or paved to reduce erosion or to prevent percolation of water into pervious areas on the benches.

In High and Moderate hazard zones, afforestation scheme should be implemented. It is also recommended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, future land use activity has to be properly planned.

Conclusion

In conclusion, the landslide hazard zonation study provides crucial information for Aibawk rural development to understand and manage the risks associated with landslides. By integrating the current work findings into land-use planning, implementing mitigation measures, and enhancing community preparedness, the region can minimize the potential impact of landslides and foster a safer living environment for its residents.