Landslide Hazard Zonation Mapping of Hnahthial Town, Mizoram, India Using Remote Sensing & GIS

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***Abstract*— Large area of Mizoram is prone to landslides. The main causes of slope instability in the region are attributed to immature geology, high slope and relief, heavy rainfall and improper land use practice. In the present study, Landslide Hazard Zonation (LHZ) study of Hnahthial town has been attempted using high resolution satellite data. The lithology, geological structures, slope morphometry, relative relief and land use/land cover layers of Hnahthial town area were prepared using Satellite Remote Sensing and Geographic Information System (GIS) techniques. These were classified, ranked and weighted according to their assumed or expected importance in causing slope instability based on apriori knowledge of the experts. A heuristic method has been applied for the assignment of ranks and weights. Landslide hazard zonation map is generated showing five hazard classes ranging from very low hazard to very high hazard.**

***Index Terms*— GIS, Hnahthial, Heuristic, Landslide Hazard Zonation, Remote Sensing.**

I. Introduction

Landslides are a form of mass movement, which can be described as a rapid down slope movement of soil, sediments and rocks due to gravity [1]. Landslide has become one of the most damaging hazards on the earth in recent years [2]. Landslide can be a disaster causing destruction of lives and properties when it occurs within the settlement. The slope of an area, its geomorphological feature, climate and anthropogenic activities play important roles in triggering the process. Mizoram, being a hilly terrain, is experiencing various types of slope failures, particularly during the monsoon season. This creates a number of miseries to the public, resulting in loss of life and property, disruption of communication network, and also cause economic burden in the society.

Geologically, Mizoram is a part of Tripura-Mizoram miogeosyncline, which in turn belongs to the broad Assam-Arakan geosynclinal basin. The area is represented by a repetitive succession of argillaceous and arenaceous sediments of Palaeogene-Neogene age. The general trend of the rock formations is N-S with dips varying from 20^o to 50^o either towards east or west [3]. The main causes of slope failure in Mizoram are primarily concerned with the surface factors rather than the sub-surface factor and/or seismic or volcanic activity which seldom or never occurred in the region. As Mizoram forms a part of Himalayan mobile belt, neo-tectonic activity and its associated factors have played considerable roles in generating slope failure to a large extent, especially in the geologically unstable areas like proximity to active fault zones, unconformity, etc. The region is geologically young, and the lithology is mainly represented by unstable and soft sedimentary rocks, which, when subjected to an intense spell of rain are easily prone to slide down along the slope. Besides, high slope and relief and improper land use practice in the State have also catapulted frequency of landslide occurrence in the region. These made the region highly susceptible to landslides.

Hnahthial town has been experiencing a steady growth in urbanisation. Various developmental activities are being taken up within the town. Unfortunately, these have been carried out without sufficient consideration of the existing slope instabilities. This results in various types of land subsidence along the slopes. This recurring disastrous event within the town and its surroundings warrant a detailed study to identify the hazard-prone areas in terms of slope instability, so that suitable mitigation measures can be taken up beforehand. Though these movements cannot be stopped from occurring, their effect can be minimized through suitable mitigation measures for reducing their frequency and severity [4].

Reports on landslide studies and its geology within Hnahthial town, in particular are very meager. Tiwari *et al.* (1997) [3] have done exhaustive work on LHZ mapping along Hnahthial - Hrangchalkawn road section at 1:50,000 scale, wherein some parts of Hnahthial town area were covered in this study. The geology, slope, relative relief and land use / land cover were studied to generate the landslide hazard zonation map of the study area. No other works of this kind have been taken up for Hnahthial town.

In recent years, with the advent of Remote Sensing and GIS techniques, landslide hazard zonation studies have become more advanced and operative [5]. The techniques have opened new perspectives for carrying out evaluation, management and monitoring of natural hazards with better results and more economical measures than is possible with conventional methods. Apart from several studies, Landslide Hazard Zonation (LHZ) using Remote Sensing and GIS techniques have been carried out in Bhagirathi Valley [6], Uttaranchal and Himachal Pradesh [7], Darjeeling Himalaya [8], Sikkim Himalaya [9], Aizawl town [10] & [11], Dikrong river basin [12], Kohima town [5], Kullu District [13], South Sinai, Egypt [14], Giri Valley [15], Nilgiri district [16], Serchhip town [17], Mamit town [18], Saitual town [19], Kolasib town [20] and Aizawl district [21]. It has been proven from the previous studies that high resolution satellite data are useful for micro-level landslide hazard zonation in hilly areas.

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Keeping all these in mind, landslide hazard zonation mapping of Hnahthial town at 1:5,000 scale was taken up for undertaking mitigation measures, and to identify suitable areas for future developmental activities within the town.

II. MATERIALS AND METHODS

A. *Study Area*

Hnahthial town is one of the large settlements within Lunglei district of Mizoram with an area of 5.15 sq. km and is located between 92° 55′ 03" E to 92° 56′ 20" E longitudes and 22° 59′ 03" N to 22° 56′ 40" N latitudes. It falls under Survey of India topo sheet No. 84B/13. It is linked by National Highway 54 with Aizawl, the state capital of Mizoram at a distance of 172 km, and of 60 km. from Lunglei town, the district headquarters. The entire district is under the direct influence of south west monsoon, with average annual rainfall of 2527.70 mm [22]. Location map of the study area is shown in Fig. 1.

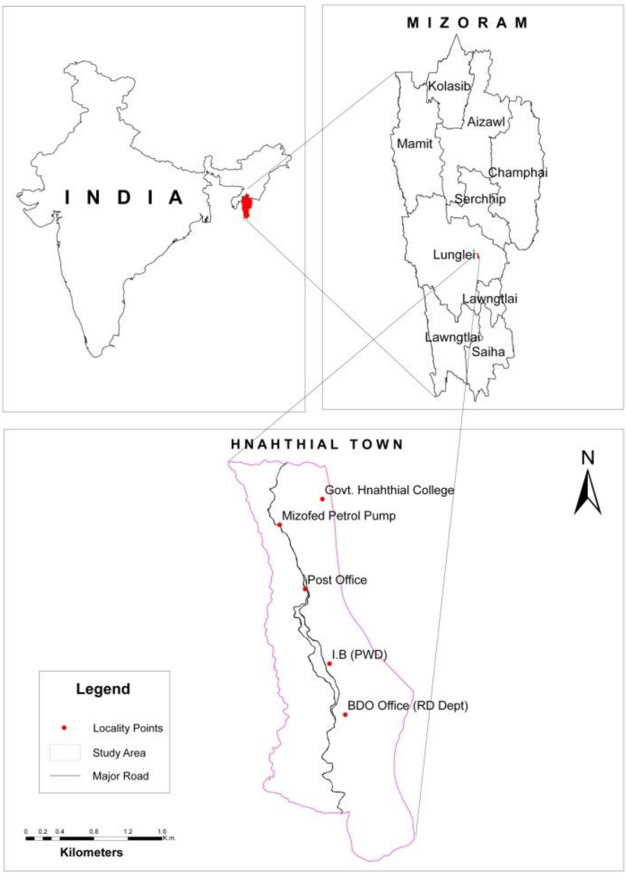

Fig. 1. Location Map of the Study Area

B. *Data Used*

Quick bird satellite imagery having spatial resolution of 0.8 m was used as the main data. Indian Remote Sensing Satellite (IRS-P5) stereo-paired Cartosat-I data having spatial resolution of 2.5 m was also used to generate Digital Elevation Model (DEM) of the study area, from which contour map is subsequently generated. In addition to this, Survey of India (SOI) topographical maps and various ancillary data were also referred. Ground truth survey was conducted to verify maps and incorporate relevant ground information.

C. *Thematic Layers*

The following thematic layers have been prepared using standard Remote Sensing and GIS techniques, and were utilized as parameters for giving weightage and for generating different landslide hazard classes.

Land Use / Land Cover

Land use / land cover is one of the important factors that controls the occurrence of landslides. It is an indirect indication of stability of hill slopes because it controls the rate of weathering and erosion of the underlying rock formations. The study area is divided into six land use / land cover classes, viz., Heavy Vegetation, Light Vegetation, Built-up, Scrubland, Barren and Water body. Areas covered by heavy vegetation are found to be least susceptible to landslide. Hence, Heavy Vegetation class is assigned low weightage value. Barren and Built-up areas are more prone to landslide than those of other classes and are given high weightage values. The statistics of land use/land cover is shown in Table I, and the map is shown in Fig. 2**.**

Table I Land Use/ Land Cover Statistics

Land Use Class	Area (in Sq. Km.)	Area (in %)
Heavy Vegetation	1.50	29.18
Light Vegetation	0.82	15.91
Built up	0.64	12.38
Scrubland	2.09	40.64
Barren	0.09	1.84
Water Body	0.00	0.05
Grand Total	**5.15**	**100.00**

Slope

Digital Elevation Model (DEM) of the study area was generated from the IRS-P5 stereo-paired Cartosat-I data. The DEM has been utilized to derive the slope map in a GIS environment. Slope is one of the important factors of landslide incidences. Landslides are more prevalent in the steep slope areas than in moderate and low slope areas [9]. The shear stress in soil or other unconsolidated material generally increases as the angle of slope increases. Therefore, slope is one of the most important parameter for stability consideration [23]. Landslides are more prevalent in the steep slope areas than in moderate and low slope areas [9]. The slopes of the area are represented in terms of degrees, and are divided into seven slope facets, viz., 0-15, 15-25, 25-30, 30-40, 40-45, 45-60 and above 60 degrees. Weightage values are assigned in accordance with the steepness of the slope, where steeper slope has higher weightage value than gentler slope. The slope statistics is given in Table II, and slope map is shown in Fig. 3.

Relative Relief

Relative relief plays a crucial role in the vulnerability of settlements, transport network and land. Hence, it is an important factor in landslide hazard zonation [13]. The study area possesses high relative or local relief and was divided into High, Moderate and Low classes with elevation ranging from more than 1000m, 500-1000m and less than 500m from mean sea level respectively. High elevated areas are more susceptible to landslide than areas with lower elevation [23] and following this pattern, weightage values were given to each of the relative relief classes. The area coverage of different relative relief classes is given in Table III and relative relief map of the study area is shown in Fig. 4.

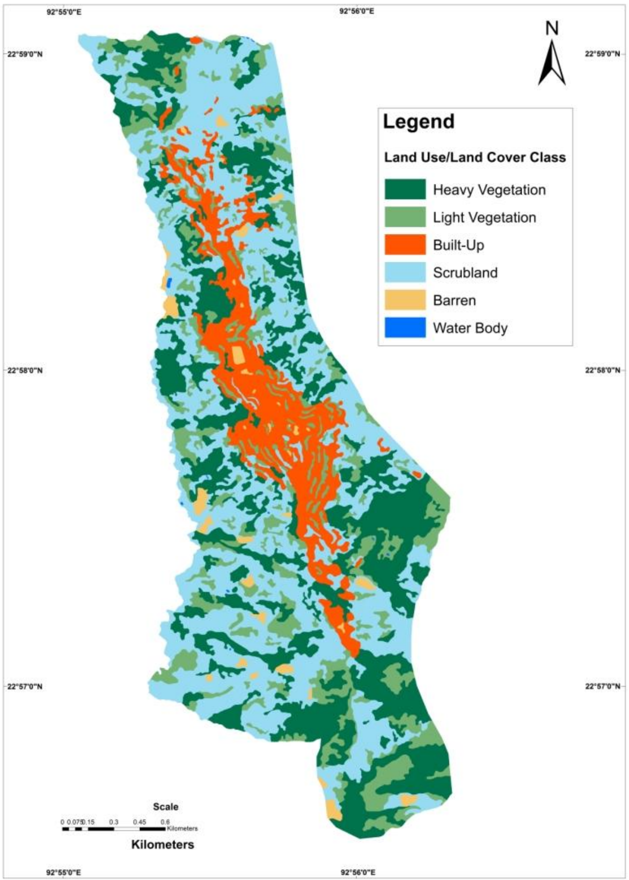

Fig. 2. Land Use / Land Cover Map

Table II Slope Statistics

Degree of Slope	Area (in Sq. Km.)	Area (in %)
0-15	1.54	29.90
15-25	1.97	38.31
25-30	0.75	14.52
30-40	0.51	9.97
40-45	0.29	5.72
45-60	0.07	1.32
>60	0.01	0.25
Grand Total	**5.15**	**100.00**

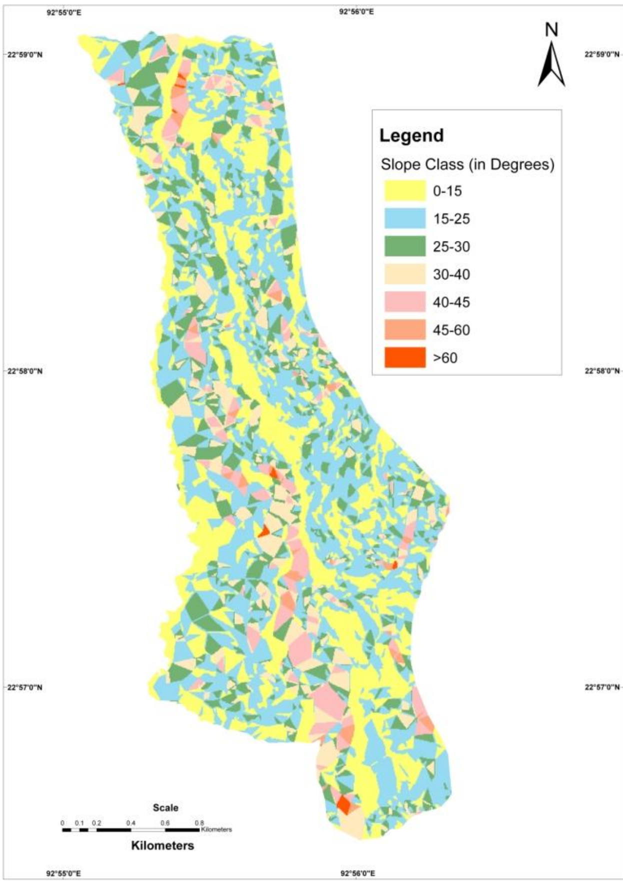

Fig. 3. Slope Map

Table III Relative Relief Statistics

Relative Relief Unit	Area (in Sq. Km.)	Area (in %)
Relatively High Relief	0.29	5.56
Relatively Moderate Relief	2.46	47.85
Relatively Low Relief	2.40	46.58
Grand Total	**5.15**	**100.00**

Lithology

The study area is composed of rocks of Middle Bhuban and Upper Bhuban Formation of Surma Group. It exposes limited rock types, viz. sandstones, shales and siltstones, and their intermixtures in varying proportions [3]. The Middle Bhuban Formation is conformably underlain by the Upper Bhuban Formation with gradational and transitional contact. The Middle Bhuban Formation is mainly argillaceous with shale as the dominant rock type. It consists of assemblage of shale, siltstone, sandy shale and clayey bands with subordinate amount of sandstones. The Upper Bhuban Formation is mainly arenaceous with sandstone as the dominant rock type. It comprises of sandstone with subordinate amount of shale, siltstone with occasional clay bands. Five litho-units have been established for the study area purely based on the exposed rock types of the area. These are named as sandstone, shale-siltstone, siltstone-shale, crumpled shale and gravel-silt unit. It may be noted that the demarcation and correlation of the two formations is extremely difficult owing to more or less uniform lithological characters and absence of marker horizons and index fossils. For the occurrence of landslide, crumpled shale unit is the most susceptible rock type, followed by shale-siltstone unit. In accordance with this, weightage values are assigned for each of the rock types. The statistics of lithology is given in Table IV.

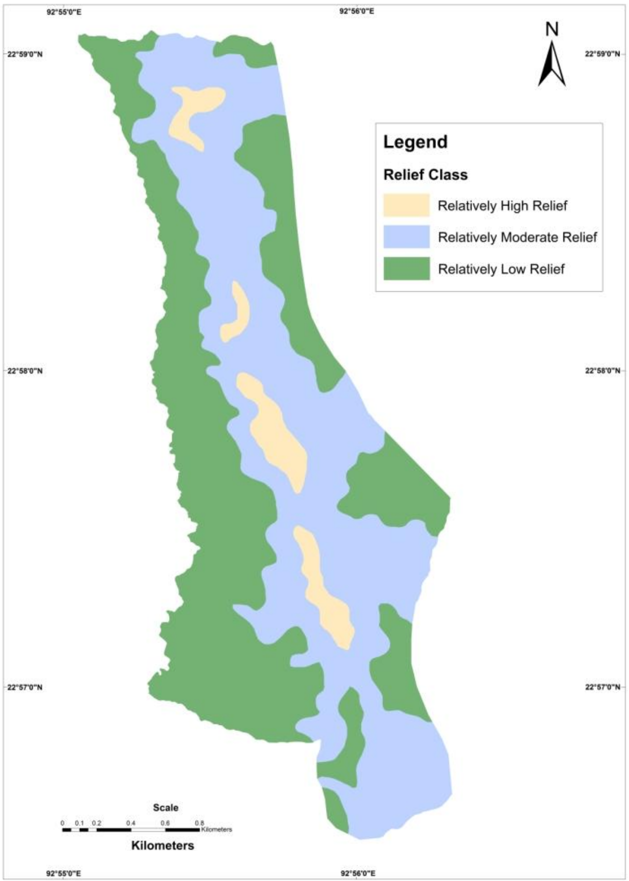

Fig. 4. Relative Relief Map

Table IV Lithological Statistics

Rock Types	Area (in Sq. Km.)	Area (in %)
Sandstone	0.07	1.27
Shale- Siltstone	2.50	48.45
Siltstone-Shale	2.48	48.06
Crumpled Shale	0.06	1.22
Gravel-Silt	0.05	1.01
Grand Total	**5.15**	**100.00**

Geological Structure

Structurally, the study area is represented by a NW-SE trending of the anticlinal core of Hnahthial anticline. The beds generally trend N-S to roughly NNW-SSE and dip on either side from 20^o to 65^o with local variations. Besides bedding planes, two to three sets of joints have been noted [3]. The lineaments are well distributed within the study area, and are oriented in various directions. Few faults of small magnitude have been identified which are mostly transverse/oblique in disposition. Geological features like faults, fractures, joints, etc. can be observed and measured using Remote Sensing data [24]. Structure and lithology are amongst the most important parameters for Landslide Hazard Zonation [25]. Areas located within the vicinity of faults zones and other geological structures are considered more vulnerable to landslides. The geological map is shown in Fig. 5.

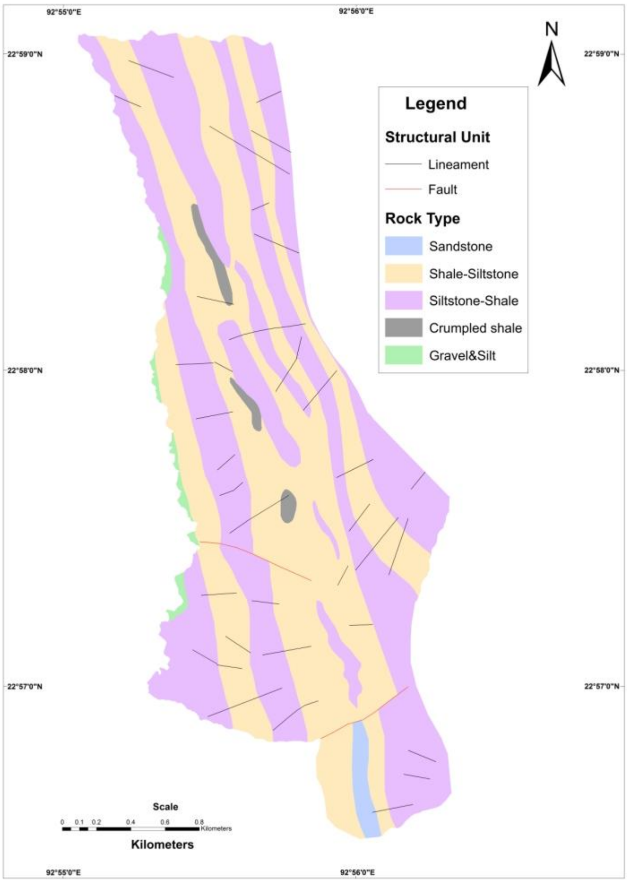

Fig. 5. Geological Map

III. METHODOLOGY AND DATA ANALYSIS

Landslide Hazard Zonation may be defined as a technique of classifying an area into zones of relative degrees of potential hazards by ranking of various causative factors operative in a given area based on their influence in initiation of landslides. Thus, the LHZ of an area aims at delineating the landslide potential zones and ranking them in order of the degree of hazard from landslides.

The heuristic method is an indirect (or semi-direct) method which involves simple ranking and weighting methods for landslide hazard zonation that relies on the *apriori* knowledge of landslides and their processes within the study area. The advantage of this method is that a landslide inventory is not needed because the weights and ranks are assigned on *apriori* knowledge of the experts [2]. The first step involves selection of causative factors of slope instability in the area of interest. Consequently, five causative factors viz., lithology, structure, slope morphometry, relative relief and land use/land cover were considered in the present study. Each causative factor was converted to a thematic map. Each parameter is carefully analysed so as to establish its relation to landslide susceptibility. The relative importance of each parameter for landslide is evaluated according to subjective opinion based on the *apriori* knowledge of the experts. Accordingly, rank values were assigned to each parameter, starting from 1 to 100, with 1 and 100 being the least and the most important in inducing landslides respectively. Among the various causative factors considered, slope is found to be the most influencing factor for slope instability within the study area. Hence, the highest rank value was assigned to it. Similarly, different rank values were assigned to the remaining parameters based on the relative importance towards landslide occurrence. The sum of the ranks of all parameters equals 100.

Each parameter was classified into a number of classes based on the relative influence of slope instability. Each class was assigned an ordinal rating (weight) from 0 to 10. The weight values of each class within a parameter were attributed on the basis of its importance in causing mass movements. For example, in the lithology layer, the crumpled shale unit offers more chance of slope failure than the hard and compact sandstone unit. Similarly, areas located within the vicinity of fault zones and other geological structures are more vulnerable to landslides and other mass movements. For this, areas 50 m on both sides of all the lineaments including faults are buffered. Likewise, due considerations are given for the relation between landslides and other classes of a parameter, and different weight values were assigned accordingly. Summation of these attribute value were then multiplied by the corresponding rank value to yield the different zones of landslide hazard. The distribution of ranks and weights for different parameters and their classes are given in Table V, and the flowchart for methodology is shown in Fig. 6.

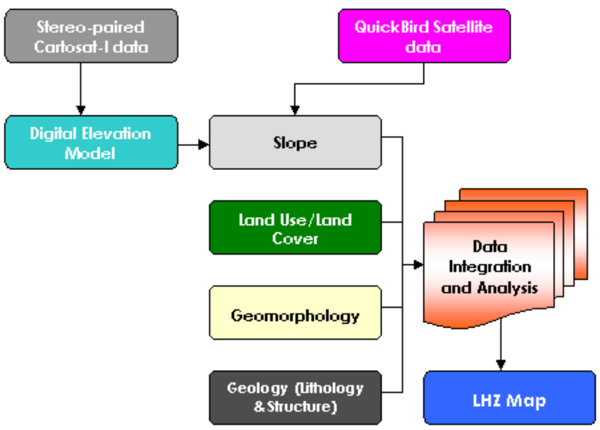

Fig. 6. Flowchart for Methodology

Table V Parameters and their ranking in terms of their influence to Landslides

Parameter	Rank	Category	Weight
Land Use / Land Cover	15	Heavy Vegetation	3
		Light Vegetation	5
		Built-up	8
		Scrubland	6
		Barren	7
		Water Body	0
Slope Morphometry (in degrees)	35	0-15	2
		15-25	4
		25-30	6
		30-40	8
		40-45	5
		45-60	4
		>60	3
Relative Relief	10	Relatively High Relief	4
		Relatively Moderate Relief	3
		Relatively Low Relief	2
Lithology	25	Sandstone	4
		Shale- Siltstone	8
		Siltstone-Shale	7
		Crumpled Shale	10
		Gravel-Silt Unit	5
Geological Structure	15	Length of Buffer distance on either side	8

IV. RESULTS & DISCUSSIONS

Combining all the controlling parameter, and by giving different weightage value for all the themes, the final LHZ map is derived on the scale of 1:5,000. The area statistics of the landslide hazard zones are given in Table VI, and the Landslide Hazard Zonation (LHZ) map of the study area is shown in Fig. 7. The study area is categorized into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' hazard zones. Various hazard classes are described below:

A. Very High Hazard Zones

This zone is highly unstable, and is at a constant threat of landslides, especially during and after an intense spell of rain. This zone has steep slopes with loose and unconsolidated materials, and includes areas where active landslides had occurred. This zone is dispersed in few places as found below Rallang Tlang and St. Stephen's School, along Aizawl road, below Govt. Hnahthial College, below Nauhruaikawn along Lunglei road and is found along Bung lui near Chanmari Cemetery. Apart from these, the very high hazard zone is found to be scattered in small pockets at various parts within the town. It also includes areas where road cutting and other human activities are actively undertaken. In addition, it is also found along the streams along Khamrang lui located at Lunglei road, where toe-erosional activities are constantly taking place. The vegetation in this zone is generally scarce. The rocks exposed are characterized by numerous bedding and joint planes which facilitate the chance of sliding down along the slope. This zone constitutes an area of 1.01 sq. km and forms 1.84% of the total study area.

It is recommended that no human induced activity be undertaken in this zone. It will be difficult to develope economically and socially acceptable remedial measures which can prevent recurrence of the hazard. Hence, such areas have to be entirely avoided for settlement or other developmental purposes.

Table VI Landslide Hazard Zonation Statistics

Hazard Zone	Area (in Sq. Km.)	Area (in %)
Very High Hazard Zone	0.08	1.54
High Hazard Zone	0.66	12.92
Moderate Hazard Zone	2.72	52.80
Low Hazard Zone	1.65	32.04
Very Low Hazard Zone	0.04	0.70
Grand Total	**5.15**	**100.00**

Plate 1. Retaining wall being constructed to check further subsidence along Lunglei road

B. High Hazard Zone

This zone includes areas where the probability of sliding the debris is at a high risk due to weathered rock and soil debris covering steep slopes which when disturbed are prone to landslides. Many of the pre-existing landslides occurred within this zone. Besides, this zone includes some areas where the dip direction and slope direction, which are usually very steep, are the same. This rendered them susceptible to sliding along the slope. 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, also fall under this class. The High Hazard Zone is distributed in many parts of the town area. It always surrounds the Very High Hazard Zone. This zone is found along Lamhnai Mawng lui, Peniel Veng, Lunglei-Aizawl road, Electric Veng, along Arbawh lui, Electric Veng, etc. Vegetation is generally either absent or sparse. The High Hazard Zone is also found along the intersection of steep slope with road cutting. This zone occupies an area of 12.92 sq. km which is 0.66% of the total study area.

Allocation and execution of major housing structures and other projects within this zone should be discouraged. If unavoidable circumstances compel the execution of such activity, precaution should be taken in consultation with the geological experts. Unless immediate action plans are implemented, this zone will soon deteriorate to the critical situation.

C. Moderate Hazard Zone

This zone is generally considered stable, provided its present status is maintained. It comprises areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. Although this zone may include areas that have steep slopes (more than 45 degree), the orientation of the rock bed or the absence of overlying loose debris and human activity may make this zone less hazardous. The Moderate Hazard Zone is distributed in various parts of the study area. Several parts of the human settlement also come under this zone. This zone covers an area of 52.80 sq. km. and occupies 2.72% of the total study area.

Although this zone is generally considered stable, it may contain some pockets of unstable zones in some areas. Such areas need to be identified on the ground and suitable mitigation measures should be undertaken. It is recommended that human activity that can destabilize the slope and trigger landslides should not be undertaken within this zone. Although this zone comprises areas which are stable in the present condition, future land use activity has to be properly planned so as to maintain its present status.

Plate 2. Road being disrupted by landslide occurred below Hnahthial College

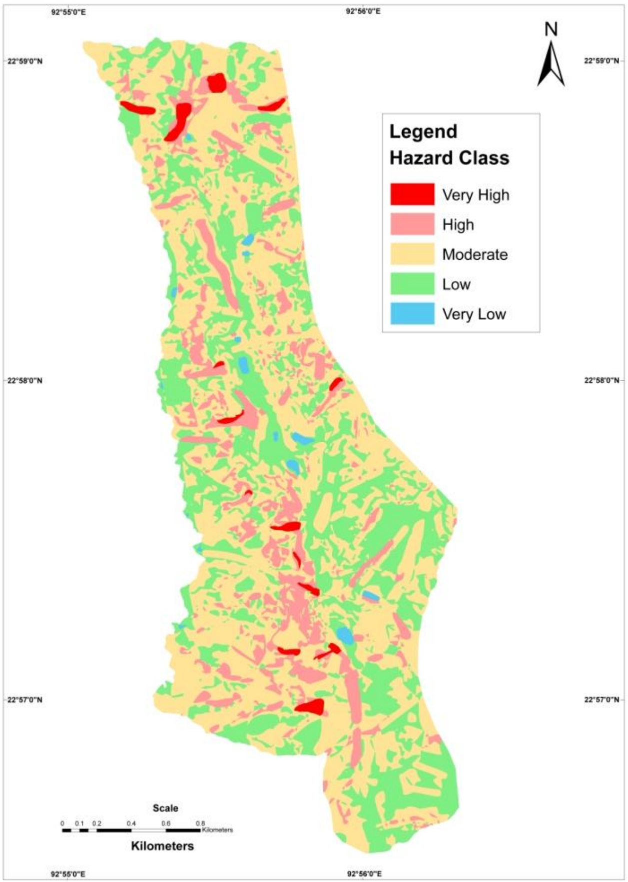

Fig. 7. Landslide Hazard Zonation Map

D. Low Hazard Zone

This zone includes areas where the combination of various controlling parameters is not having adverse influence on the stability of the slope. In other words, this zone comprises areas where the chance of slope failure is low or unlikely to occur by virtue of its present environmental set up. Vegetation is relatively dense, except in some areas. Although some of the areas may be covered with soft and unconsolidated sediments, the slope angles are generally low, about 30 degrees or below. Flat lands and areas having low degrees of slope fall under this class. This zone is mainly confined to areas where anthropogenic activities are less or absent, and are mainly distributed along the periphery of the study area. This zone covers an area of 32.04 sq. km. and forms 1.65% of the total study area.

No evidence of slope instability is observed and mass movement is not expected within this zone. Therefore, this zone is suitable for carrying out developmental schemes. Developmental activities are considered safe to be carried out within this zone.

E. Very Low Hazard Zone

This zone generally comprises areas covered by dense vegetation and is mostly located away from human settlement. In addition, it includes valley fill and other flat lands. Therefore, it is assumed that this zone is free from the present and future landslides. The dip direction of the rocks and slope angles 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 and vegetative cover. This zone covers an area of 0.70 sq. km., and forms 0.04% of the total study area.

As far as slope stability is concerned, developmental activities of any kind can be safely carried out within this zone. Most of the areas within this zone can be allocated for major housing structures without hesitation.

V. CONCLUSION

In the present study, it is observed that human activities coupled with natural factors like lithology, slope, geological structure, rainfall, etc. have caused some parts of Hnahthial town highly prone to landslides. In this situation, it is necessary to have proper mitigation plan for future developmental activities, particularly in the areas falling under Very High and High hazard zones. The study also revealed that there are many stable areas where developmental activities can be taken up.

It has been proven that, a combination of Quickbird imagery for interpretation and Cartosat-I stereo data for DEM and slope generation, supported by detailed ground truthing can be utilised for producing reliable large scale geological map and landslide hazard zonation map with high accuracy in the hilly areas. The outcome map of this study will therefore, be a useful database for undertaking mitigation measures, and also for selecting viable sites for carrying out future developmental schemes within Hnahthial town.

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