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Landslide Hazard Zonation Of Lawngtlai Town, Mizoram, India Using High Resolution Satellite Data

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ABSTRACT : *Landslides are predominant natural disasters occurring in hilly terrains, often characterized by rugged hills with steep slope associated with loose unconsolidated soil. With its peak occurrences during the monsoon season, the magnitude of its effect can be disastrous depending on certain additional controlling factors - both natural and man-made. This necessitates the analysis and preparation of landslide hazard zones which would be helpful for disaster mitigation and developmental planning activities. The present study encompasses the spatial analysis of landslide prone areas in Lawngtlai town using high resolution satellite data along with field data in a GIS environment. The analysis includes various terrain parameters like, lithology, geological structures, slope morphometry, geomorphology and land use/land cover for deriving landslide hazard zones in the town. The various parameters were classified, ranked and weighted according to their assumed or expected importance in inducing 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 prepared showing five hazard classes ranging from very low hazard to very high hazard. The study indicates that a majority of the town area falls under Moderate hazard zones, which further signifies that slope stability is still a major concern when taking up developmental activities. In this context, the landslide hazard zonation map prepared in the present study will be useful for carrying out mitigation programmes as well as for planning and implementation of future developmental schemes within the town.*

KEYWORDS : *GIS, Heuristic, Landslide Hazard Zonation, Lawngtlai, Remote Sensing*

I. INTRODUCTION

Landslide has become one of the damaging and frequently occurring hazard in the hilly regions like Mizoram. Landslides occur more frequent within the towns where anthropogenic activities take place causing damage to the road sector and residential areas [1]. Landslides not only inflicts the loss of life but also property and above all the environment. It becomes a disaster causing destruction of lives and properties when it occurs within the town or other human habitations [2].

Urbanization in Lawngtlai town has been increasing with a population decadal growth of 43.08% according to Census 2011. Various developmental activities are being taken up without sufficient consideration of the existing slopes instabilities. The problem of landslides become more aggregative, especially during the rainy season, though the main causative factors for the instability are often geological and geomorphologic in nature [3]. 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 sediments of Mizoram are divided into Barail, Surma and Tipam Groups [4]. Landslides cannot be stopped from occurring, however, their effect can be minimized through suitable mitigation measures for reducing their frequency and severity [5].

Reports on landslide studies within Lawngtlai town are limited and sites prone to landslides should, therefore, be identified in advance so that corrective measures could be taken up to prevent disasters caused by it. On a broader perspective, preliminary landslide hazard zonation mapping of south Mizoram at 1:50,000 scale was undertaken by the Geological Survey of India [6]. In addition to this, more detailed landslide studies for major townships including Lawngtlai town was also done, examining the possible causes of slope failure, and suggestions for remedial measures were also made. Remote Sensing and GIS techniques for landslide hazard zonation studies have become more advanced and operative [7].

These 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. Elsewhere, Landslide Hazard Zonation (LHZ) using Remote Sensing and GIS techniques have been conducted in Bhagirathi Valley [8], Uttaranchal and Himachal Pradesh [9], Darjeeling Himalaya [10], Sikkim Himalaya [11], Aizawl town [12], Dikrong river basin [13], Kohima town [7], Kullu District [2], South Sinai, Egypt [14], Giri Valley [15], Nilgiri district [16], Serchhip town [17], Mamit town [18] and Lunglei town [19]. High resolution satellite data have proven to be useful for micro-level landslide hazard zonation in hilly areas. The present study focuses on mapping of landslide hazard zones in Lawngtlai town which would further benefit activities concerned with mitigation measures, and identifying suitable areas for infrastructure development in the town.

II. MATERIALS AND METHODS

2.1 Study area

Lawngtlai town is the administrative headquarters of Lawngtlai district with an area of 53.76 sq. km. It is located between 92^o 51′ 40" E to 92^o 56′ 12" E longitudes and 22^o 28′ 20" N to 22^o 34′ 58" N latitudes. The town falls under Survey of India topo sheet No. 84B/14 and 84B/15. It is linked by National Highway 54 with Aizawl, the state capital of Mizoram at a distance of 296 km. The town is situated towards the eastern fringe of Lawngtlai district (Fig.1) and shares the direct influence of south west monsoon, with average annual rainfall of 2510.30 mm [20]. According to Census 2011, the total population of the urban town area is 20889, which in turn indicates an increased anthropogenic activities in the town under various socio-economic development schemes.

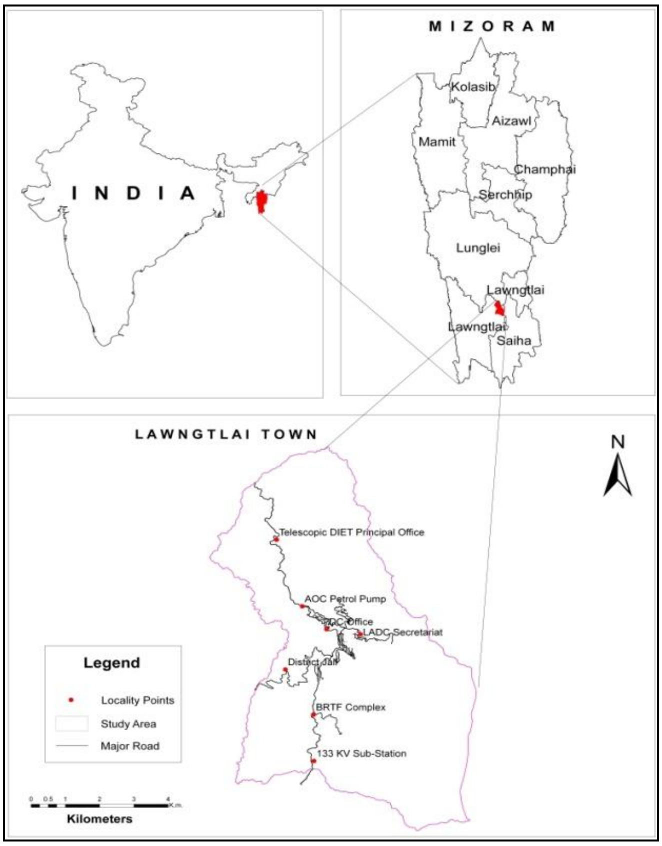

Fig. 1. Location Map of Study area

2.2 Data used

The main data used for interpretation is Quick bird satellite imagery which has a spatial resolution of 0.8 m. Cartosat-I stereo-paired data having spatial resolution of 2.5 m was also used to generate Digital Elevation Model (DEM) and contour maps of the study area. Survey of India (SOI) topographical maps and various ancillary data were also referred. Extensive ground truth surveys were conducted to verify maps and incorporate relevant ground information during the study.

2.3 Thematic layers

The thematic layers required for preparing landslide hazard zones in the study area were generated using the interpretation and analysis techniques of Remote Sensing and GIS. These layers were also utilized as parameters for assigning weightage for different landslide hazard classes.

2.3.1 Land use / land cover

Land use / land cover 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/No Vegetation and Water body. The areas covered by heavy vegetation are found to be least susceptible to landslide. Hence, Heavy Vegetation class is assigned low weightage value. Barren Land 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 1, and the map is shown in Fig. 2.

Table 1. Land Use/ Land Cover Statistics

Land Use Class	Area (in Sq. Km.)	Percentage
Heavy Vegetation	5.77	10.74
Light Vegetation	17.14	31.87
Built up	1.14	2.12
Scrubland	27.90	51.90
Barren/No Vegetation	1.66	3.09
Water Body	0.15	0.28
Grand Total	**53.76**	**100.00**

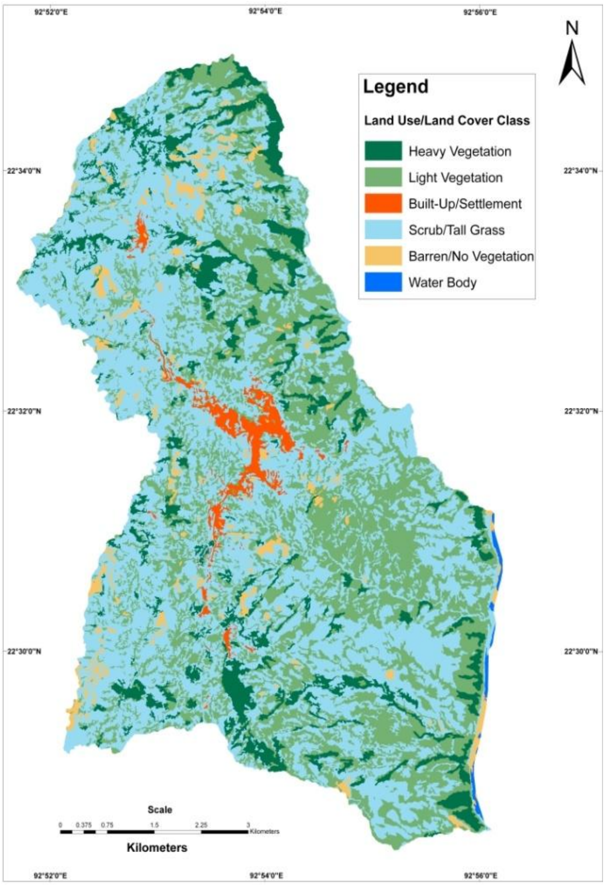

Fig. 2. Land use/land cover map of the study area

2.3.2 Slope

Slope plays an important role amongst the causative landslide factors as it represents the physical terrain conditions. Landslides are more prevalent in the steep slope areas than in moderate and low slope areas [11]. The western aspects of the middle and the eastern parts, along Vengpui locality of the study area are characterized by very steep slope. Steep hillside slopes are also noticed in few places. The southern parts of the study area, around College Veng, on the other hand, are characterized by low and gentle slope. The slopes of the area are represented in terms of degrees, and are divided into five slope facets, viz., 0-15, 15-25, 25-30, 30-35, 35-40, 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 2, and slope map is shown in Fig. 3.

Table 2. Slope Statistics

Degree of Slope	**Area (in Sq. Km.)**	**Percentage**
0-15	11.37	21.16
15-25	17.33	32.23
25-30	7.92	14.72
30-35	6.74	12.55
35-40	4.65	8.65
40-45	2.34	4.35
45-60	2.09	3.89
>60	1.32	2.45
Grand Total	**53.76**	**100.00**

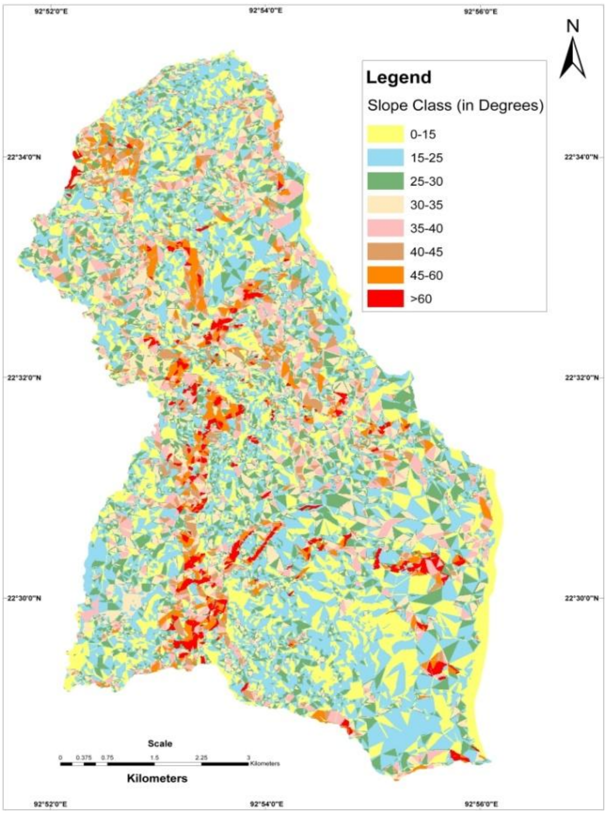

Fig. 3. Slope map of the study area

2.3.3 Geomorphology

The study area comprises of highly dissected, undulating and moderately sloping structural hill ranges. Some of the hillocks are highly dissected with sharp ridges and steep slopes, whereas some areas are characterized by gentle and low dissected hillocks. This indicates that the topography is immature. A few flat lands are mostly confined along the streams and between the spurs. Geomorphologically, the whole area is divisible into Medium Structural Hill, Low Structural Hill and Valley Fill. High elevated areas are more susceptible to landslide than low elevated areas. The statistics of geomorphology is given in Table 3 and geomorphological map of the study area is shown in Fig. 4.

Table 3. Geomorphology Statistics

Geomorphic Unit	Area (in Sq. Km.)	Percentage
Medium Structural Hill	12.92	24.04
Low Structural Hill	40.35	75.05
Valley Fill	0.09	0.16

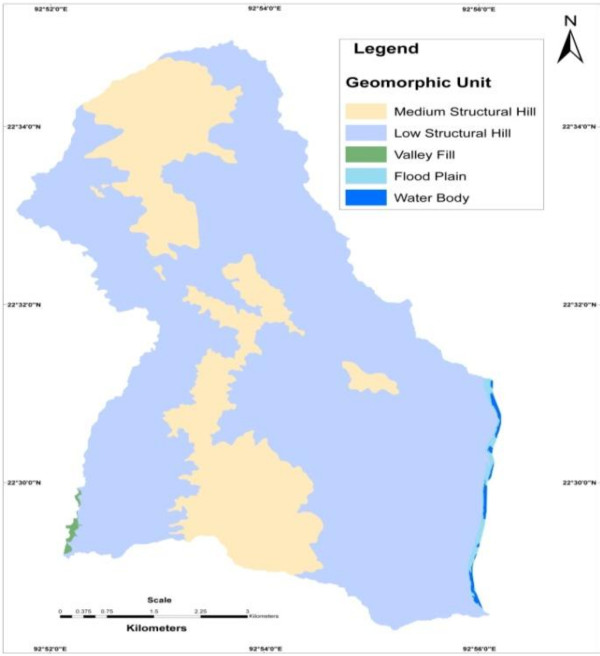

Fig. 4. Geomorphology map of the study area

2.3.4 Lithology

The study area is composed of rocks of Middle Bhuban and Upper Bhuban Formation of Surma Group [8]. It exposes limited rock types, viz. sandstones, shales and siltstones, and their intermixtures in varying proportions. 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. Six 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-sandstone, siltstone-shale, shale-siltstone, 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. The statistics of lithology is given in Table 4.

Table 4. Lithological Statistics

Rock Types	Area (in Sq. Km.)	Percentage
Sandstone	7.79	14.50
Shale-Sandstone	1.39	2.58
Siltstone-Shale	19.27	35.85
Shale-Siltstone	24.22	45.05
Crumpled Shale	0.60	1.10
Gravel-Silt	0.34	0.64
Water Body	0.15	0.28
Grand Total	**53.76**	**100.00**

2.3.5 Geological Structure

Structurally, 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. 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. The geological map is shown in Fig. 5.

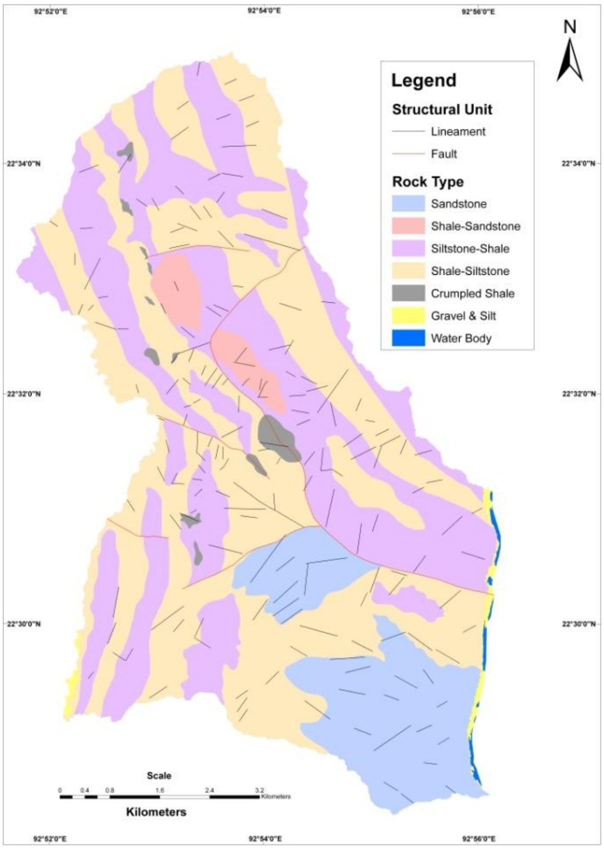

Fig. 5. Geological map of the study area

2.4 Data Analysis

The heuristic method using simple ranking and weighting methods for landslide hazard zonation was adopted in the present study. The different landslide hazard zones were identified and classified by ranking of various causative factors operative in a given area based on their influence in initiation of landslides.

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, geomorphology 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. 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 to 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 of 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 landslide hazard zones. The distribution of ranks and weights for different parameters and their classes are given in Table 5.

Table 5. Parameters and their ranking in terms of their influence to Landslide

Parameter	Rank	Category	Weight
Land Use / Land Cover	15	Heavy Vegetation	3
		Light Vegetation	5
		Built-up	8
		Scrubland	6
		Barren/No Vegetation	7
		Water Body	0
Slope Morphometry (in degrees)	35	0-10	2
		10-20	4
		20-40	6
		40-60	8
		> 60	5
Geomorphology	10	Moderate Structural Hill	3
		Low Structural Hill	2
		Valley Fill	0
		Flood Plain	0
		Water Body	0
Lithology	25	Sandstone Unit	4
		Shale-Sandstone Unit	6
		Siltstone-Shale Unit	8
		Shale-Siltstone Unit	9
		Crumpled Shale Unit	10
		Gravel-Silt Unit	7
		Water Body	0
Geological Structure	15	Length of Buffer distance on either side	8

II. RESULTS AND DISCUSSION

The final Landslide Hazard Zonation map prepared on the scale of 1:5,000 is prepared after analysing all the controlling parameter in GIS and by giving different weightage value for all the themes. The area statistics of the landslide hazard zones are given in Table 6 and the landslide hazard zonation map of the study area is shown in Fig. 7. The study area is categorised into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' hazard zones, and are described below:

2.1 Very High Hazard Zone

This zone is highly unstable, and is at a constant threat of landslides, especially during and after heavy rain. This zone has steep slopes with loose, unconsolidated materials, and also include areas where active landslides had occurred. This zone is dispersed in few places as found in Council Veng (Fig. 6), eastern side of Sobji Bazar and below LDFA Playground along Pakhawngmawng stream. It is also found scattered in small patches along Chanmari Veng, Bungtlang road and along AOC stream below AOC Filling Station. The Lower part of Lawngtlai III locality along Khurpui stream and part of Thingkah locality also falls within this zone. It also include areas where unplanned quarrying, road cutting and other human activities are active. In addition, it is also found along the streams where toe-erosional activities are constantly taking place and also in other parts of the town area in small pockets. 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 0.27 sq. km and forms 0.50% of the total study area. It is recommended that no human induced activity be undertaken in this zone. It will be difficult to develop economically and socially acceptable remedial measures which can prevent recurrence of landslide. Hence, such areas have to be entirely avoided for settlement or other developmental purposes.

Fig. 6. Massive landslide scar at Council Veng, Lawngtlai town

2.2 High Hazard Zone

This zone includes areas where the probability of sliding 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 slide along the slope. Several lineaments, fractured zones and fault planes also traverse this zone. Areas which experience constant erosion by streams because of the soft nature of the lithology and loose overlying burden, also fall under this zone. The High Hazard Zone is distributed in many parts of the town area and is found to always surround the Very High Hazard Zone. This zone is found in Vengpui, College Veng, Chandmari, Council Veng, Thingkah, AOC 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 8.70 sq. km which is 16.18% 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 can deteriorate to critical situations.

2.3 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 36.12 sq. km. and occupies 67.19% of the total study area.

Although this zone is generally considered stable, it may contain some pockets of unstable 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.

2.4 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 7.87 sq. km. and forms 14.64% of the total study area.

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

3.5 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 0.65 sq. km., and forms 1.21% of the total study area. As far as slope instability is concerned, developmental activities can be safely carried out within this zone. Most of the areas within this zone can be allocate for major housing structures.

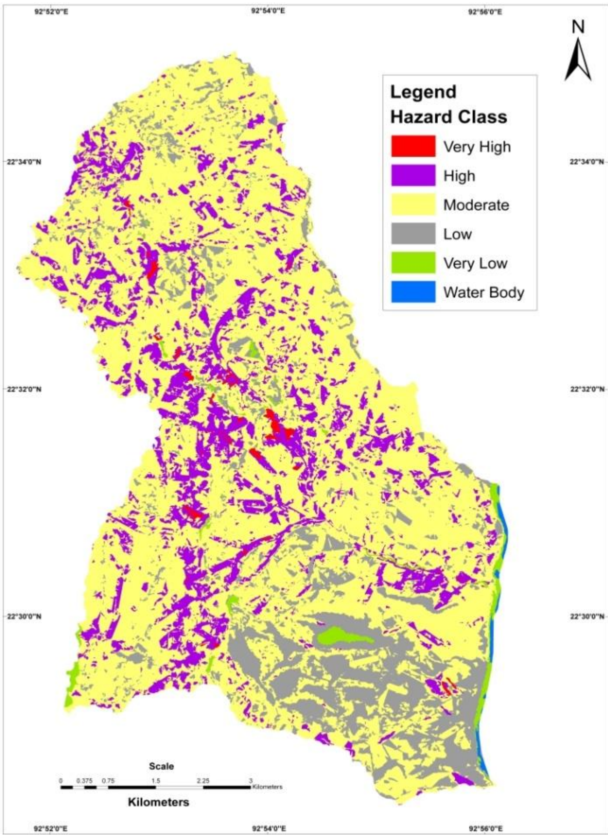

Fig. 7. LHZ map of the study area

Table 6. LHZ Statistics

Hazard Zone	Area (in Sq. Km.)	Percentage
Very High Hazard Zone	0.27	0.50
High Hazard Zone	8.70	16.18
Moderate Hazard Zone	36.12	67.19
Low Hazard Zone	7.87	14.64
Very Low Hazard Zone	0.65	1.21
Water Body	0.15	0.28
Grand Total	**53.76**	100.00

IV. CONCLUSION

The existence of landslides in the study area reveals the need to recognize the landslide characteristics, particularly in terms of its disastrous effect, mechanism and its spatial probability. It has been observed that unplanned activities coupled with inherent natural elements like lithology, slope, geological structure, rainfall, etc. have caused some parts of the town highly prone to landslides. Areas having spatial probability of landslides have been identified through the hazard zone mapping done in the present study. The landslide hazard zones prepared in this study represents an important basis for the assessment of potential hazard areas in the town. Further, mapping of these hazard zones can help decision-makers to have proper mitigation plans and for choosing suitable locations for future planning.

The use of Quickbird, Cartosat-I stereo data, supported by detailed ground truthing in a Remote sensing and GIS environment has proven the capacity of producing reliable large scale landslide hazard zonation map with high accuracy in the hilly areas. The heuristic method used in the study is an effective method for landslide hazard zonation in the Himalayan region [21], due to its ease of use without the requirement of landslide inventory[3]. The selection of the causative landslide factors in the study relies upon the consideration of relevance and availability of these factors in the study area. Hence, the selection is relative and subjective, and has scope for further replication in other hilly areas with improved flexible analysis in future studies.

V. ACKNOWLEDGEMENTS

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