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LANDSLIDE HAZARD ZONATION OF AIZAWL DISTRICT, MIZORAM, INDIA USING REMOTE SENSING AND GIS TECHNIQUES

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Abstract

Landslide is the most frequently occurring natural hazard in the tectonically active region of the Himalaya. The immature geology with high degree of slope coupled with high rainfall are the natural causes of landslide in this region. In addition, the unplanned human activities also cause landslides. The present study was taken up to investigate the Landslide Hazard Zonation (LHZ) of Aizawl district, Mizoram that consists of four urban settlements and ninety seven rural villages. Using Remote Sensing and Geographic Information System (GIS) techniques, thematic layers like slope morphometry, geological structures like faults and lineaments, lithology, relative relief and land use / land cover were generated. The weightage rating system was used for different classes of thematic layers which are based on relative importance of various causative factors. The classes were assigned corresponding rating value as attribute information in the GIS environment. Each class within a thematic layer was assigned an ordinal rating from 1 to 10. Summation of these attribute values were then multiplied by the corresponding weights to yield the different zones of landslide hazard. A landslide hazard zonation map having five different zones ranging from very low hazard zone to very high hazard zone was prepared with an objective to create reliable database for pre-disaster management and for planning developmental activities in the district.

Key words: *GIS, Landslide Hazard Zonation, Remote Sensing , weightage*

Introduction

The topography of Mizoram is geologically immature. There are N-S trending mostly anticlinal strike ridges with steep slopes and narrow intervening synclinal valleys with series of parallel hummocks or topographic highs. The other landforms are dissected ridges with deep gorges, spurs, keels, etc. Faulting in many areas has produced steep fault scarps [1]. 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 [2]. The vulnerability of human settlements to landslide is continuously increasing due to concentration of population and developmental activities in urban and rural areas. Thus, landslides can become disasters when they occur in such human habitations [3]. Populations can be highly vulnerable to natural disasters on account of high density and locations on hill slopes [4].

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 locality claimed the lives of 66 workers/inhabitants, and 17 houses were destroyed. In 1994, area 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). The area covered by this crack sunk to a depth of 4 to 5 feet below the level of the main road, 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, 1 house was completely washed away by landslide at Saikhamakawn causing death of 2 persons and injuring 4 persons. During the monsoon of 2011, Lengpui Airport road was blocked by landslide causing havoc to commuters and, within Aizawl city around 10 houses were dismantled and about 15 families were evacuated. In 2012, there was a long-line crack at Ramhlun Sport Complex area ere around 10 houses were dismantled and almost 60 families were shifted. In the same year, a massive landslide at a stone-quarry near Keifang locality (Saitual town) claimed the lives of 18 people. Recently, during the month of May 2013, there was a massive landslide at Laipuitlang locality within Aizawl city claiming the lives of 17 persons. More than 10 persons were injured, about 12 houses and 16 vehicles were damaged.

Due to the manifold miseries and problems it causes to the public, several attempts were made to study landslide within the state of Mizoram. However, district level studies on landslide for Aizawl district has not yet been carried out so far.

The previous studies include geotechnical appraisal of Bawngkawn landslide (1994), examining the causes of the slope failure and suggestions for remedial measures [5]. The possible causes of South Hlimen landslide in 1992 which claimed the lives of almost 100 people were also critically examined, and suggestions for mitigation measures were made [6]. An in-depth study of Vaivakawn landslide with geotechnical laboratory testing of the slide materials had also been carried out, and suggestions for remedial measures were made [7]. Geo-environmental appraisal of Aizawl town and its surroundings was also carried out in which the causes and remedial measures for landslides in the area were highlighted [8]. Geo-data based Total Estimated Landslide Hazard Zonation at the southern part of the state was also carried out. It was concluded that landslide hazard zonation map is of fundamental importance during planning and implementation of developmental work in a hilly state like Mizoram [9]. A comprehensive report on Landslide Hazard Zonation of south Mizoram (which include Lunglei, Lawngtlai and Saiha districts) was also done in which various causative factors of landslide were studied and recommendations for its mitigations were also given. [10]

Several researchers have attempted landslide hazard zonation using Remote Sensing and GIS techniques [11]. Using the said techniques, Landslide Hazard Zonation of Uttaranchal and Himachal Pradesh States had been carried out successfully by National Remote Sensing Agency [12]. Landslide Hazard Zonation of Aizawl city, the state capital of Mizoram using lower resolution satellite data, viz., IRS LISS III and PAN data had also been done, and it was concluded that these data can be used effectively for generating Landslide Hazard Zonation map [13]. Remote Sensing and GIS techniques have been proven to be of immense value world-over in hazard zonation, and this has been validated in the study conducted for Aizawl city [14]. The same technique has also been successfully applied in Landslide Hazard Zonation studies for Serchhip town [15] and Mamit town of Mizoram [16]. The present study utilizes IRS-P5 (Carosat-I) and IRS-P6 LISS-III to map the landslide hazard zones of Aizawl district for undertaking mitigation measures and to identify suitable areas for future development.

Study Area

Aizawl district is located in the northern part of Mizoram, in the north-east corner of India. Aizawl city, the state capital is situated within the district. With a total area of 3576.00 sq km the district is geographically located between 92^{o} 37′ 03"E to 93^{o} 11′ 45" E longitudes and 23^{o} 18′ 17"N to 24^{o} 25′ 16" N latitudes. Location map of the study area is shown in Fig. 1. The district falls under Survey of India topo sheet No. 83D/15, 83D/16, 84A/9, 84A/10, 84A/11, 84A/13, 84A/14, 84A/15,84E/1, 84E/2, 83H/3 and 83H/4. The climate of the study area ranges from moist tropical to moist sub-tropical. The entire district is under the direct influence of monsoon, with an average annual rainfall of 3155.3 mm [17].

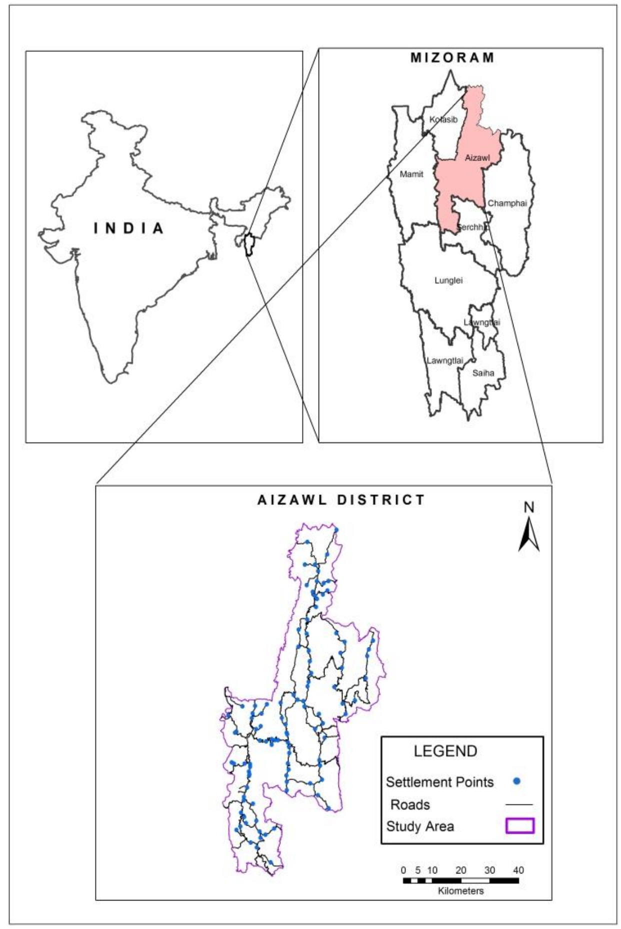

Figure 1. Location map of study area

Material and Methods

Data used

In the present study, Indian Remote Sensing Satellite (IRS-P5) stereo-paired Cartosat-I imagery having spatial resolution of 2.5 m and Indian Remote Sensing Satellite (IRS-P6) LISS III data having spatial resolution of 23.5 m were used as the main data. SOI topographical maps and various ancillary data were also referred to.

Thematic layers

As landslides are governed by several factors [18], five important causative factors were prepared as thematic layers from satellite data and field study. These thematic layers were then utilized for Landslide Hazard Zonation. The different layers are as follows-

Land use / Land cover: Land use / land cover is an important factor in Landslide Hazard Zonation as it controls the rate of weathering and erosion of the underlying rock formations. The study area was divided into five classes, viz., Heavy Vegetation, Light Vegetation, Scrubland, Built-up and water body. Areas with dense vegetation cover are considered less prone to the occurrence of landslides while all other parameters remain constant [19]. Hence Heavy Vegetation class was assigned low weightage value. Due to human interference, Built-up areas were more prone to landslide than those of other classes [20] and were given high weightage. The statistics of land use / land cover is given in Table 1 and the map is shown in Fig. 2.

Table 1. Land use/land cover statistics of Aizawl district

Land use Class	Area [Sq.Km.]	Percentage
Heavy Vegetation	1057.32	29.57
Light Vegetation	1822.93	50.98
Scrubland	633.19	17.71
Built up	48.27	1.35
Water body	14.29	0.40
Total	**3576.00**	**100.00**

Slope: 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 [21]. Landslides are more prevalent in the steep slope areas than in moderate and low slope areas [22]. Slope map was generated using IRS-P5 (Cartosat-I data) stereo-paired and Digital Elevation Model (DEM) in a GIS environment. The slopes of the area are represented in terms of degrees, and are divided into eight slope facets, viz., 0-15, 15-25, 25-30, 35-40, 40-45, 45-60 and above 60 degrees. Weightage values are assigned in accordance with the steepness of the slope. The slope statistics of the study area is given in Table 2 and slope map is shown in Fig. 3.

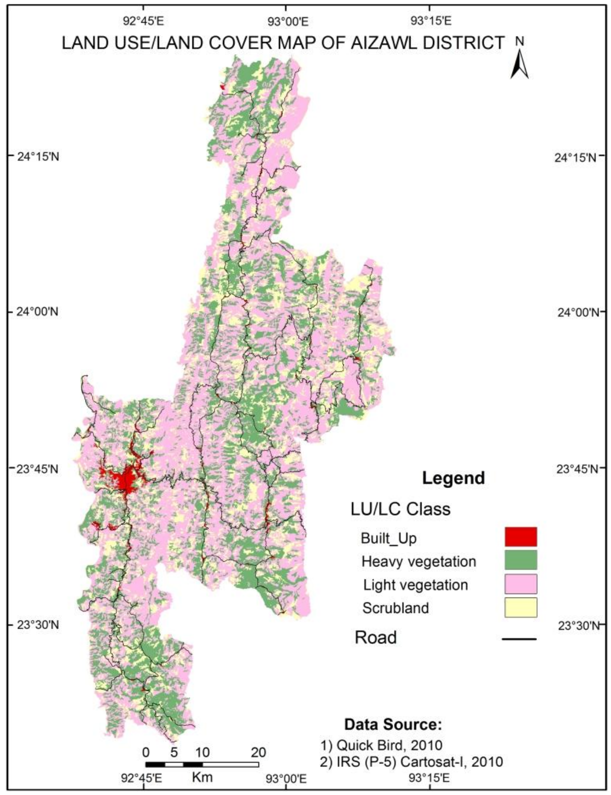

Figure 2. Land use/land cover map of Aizawl district

Table 2. Slope statistics of Aizawl district

Degree of Slope	Area [Sq.Km.]	Percentage
0-15	25.65	0.72
15-25	5.90	0.17
25-30	119.34	3.34
30-35	341.17	9.54
35-40	1370.58	38.33
40-45	1164.65	32.57
45-60	450.31	12.59
>60	98.39	2.75
Total	**3576.00**	**100.00**

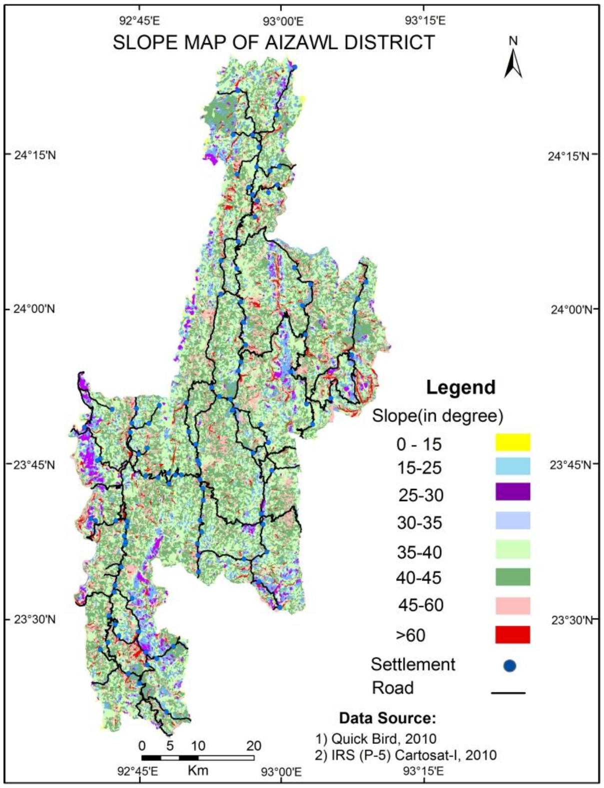

Figure 3. Slope map of Aizawl district

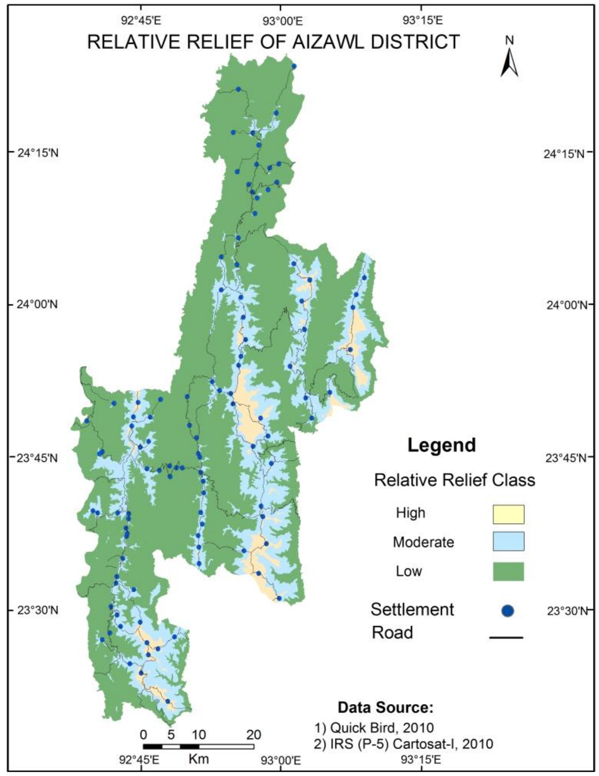

Figure 4. Relative relief map of Aizawl district

Table 3. Relative relief statistics of Aizawl district

Relative Relief Classes	Area [Sq.Km.]	Percentage
High	180.20	5.04
Medium	830.30	23.22
Low	2565.51	71.74
Total	**3576.00**	**100.00**

Relative relief: The study area possesses high relative 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 [3]. The study area was divided into High, Moderate and Low classes in term of relative relief with an elevation ranging from more than 1200m, 800-1200m and less than 800m from msl respectively. High elevated areas are more susceptible to landslide than areas with lower elevation [21]. Following this pattern, weightage values are given to each of the relative relief classes. The area coverage of different relative relief classes is given in Table 3 and relative relief map of the study area is shown in Fig. 4.

Lithology: The earliest recorded work on geology of Mizoram was conducted in 1891, and it was reported that the area consisted of great flysch facies of rocks comprising monotonous sequences of shale and sandstone [23]. Lithology is one of the most significant parameters for landslide hazard zonation [22]. The study area lies over Bhuban and Bokabil formations of Surma Group of Tertiary age which consist mainly of arenaceous and argillaceous type of rocks [1]. 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 unit, Siltstone-shale unit, Limestone unit, Gravel, Sand & Silt unit and Clayey Sand unit. Sandstone is the harder rock formation of the area and is found mainly along the ridgeline owing to its resistance to erosion. Siltstone and Shale are put together as they are almost inseparable, and this unit covers a large part of the study area. The Limestone unit is hard, compact, dark grey in colour and contains broken or complete shells. This unit is found in small outcrops at two places in the western part of the district. Gravel, Sand & Silt, and Clayey Sand units are the recent alluvium deposits which are found along the major rivers and along small streams respectively. The unconsolidated material units offer more chance of slope failure than any other units and hence highest weightage value is given. Lithological units comprising siltstone and shale are more susceptible to landslide than the hard and compact limestone and sandstone units. In accordance with this, weightage values are assigned for analysis. The statistics of lithological unit is given in Table 4.

Geological Structure: 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]. It was observed that the rocks exposed within the study area are traversed by several fault and fractures of varying magnitude and length [26]. Areas located within the vicinity of faults zones and other geological structures are considered more vulnerable to landslides. The geological map showing the geological structure is given in Fig. 5.

Table 4. Lithological statistics of Aizawl district

Rock Types	**Area [Sq. Km.]**	**Percentage**
Sandstone	1279.52	35.78
Siltstone & Shale	2264.12	63.31
Limestone	1.47	0.05
Gravel, Sand & Silt	5.36	0.15
Clayey Sand	25.52	0.71
Grand Total	**3576.00**	**100.00**

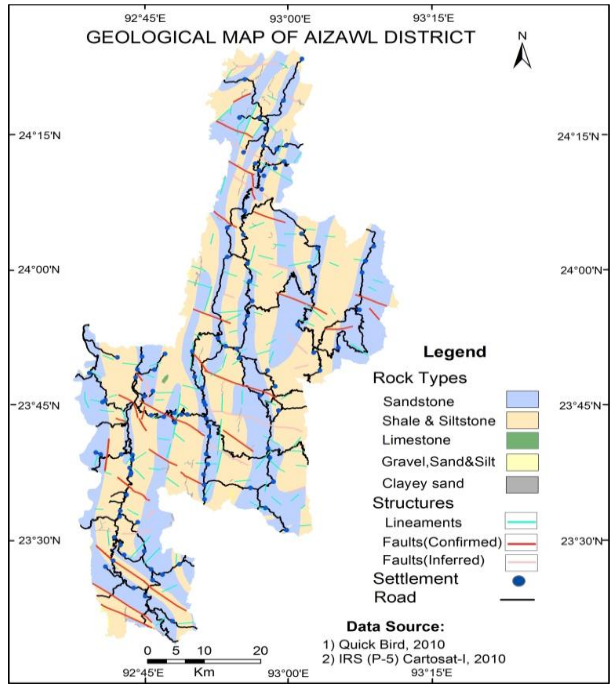

Figure 5. Geological Map of Aizawl district

Data Analysis

The geo-environmental factors like slope morphometry, land use/land cover, relative relief, 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 are carefully analysed 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 landslide based on the *apriori* knowledge of the experts. All the thematic layers we
re integrated and analysed in a GIS environment using ARCINFO (9.3 version) to derive a Landslide Hazard Zonation map. The scheme of giving weightages by National Remote Sensing Agency [12] and stability rating as devised by Joyce and Evans [27] are combined and used in the present study as depicted in Table 5.

Table 5. Ratings for Parameters on a scale of 1-10

Parameter	**Category**	**Weight**
Lithology	Sandstone	4
	Siltstone & Shale	8
	limestone	3
	Gravel, Sand & Silt	10
	Clayey Sand	10
Land Use / Land Cover	Heavy Vegetation	3
	Light Vegetation	5
	Scrubland	6
	Built-up	8
	Water body	1
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
Structure (Faults and Lineaments)	Length of Buffer distance on either side	8
Relative relief	High	4
	Medium	3
	Low	2

Results and Discussion

Combining all the controlling parameters and by giving different weightage value for all the themes, the final LHZ map is prepared and categorised into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' hazard zones. The output map is generated on a scale of 1: 5,000. Various hazard classes are described below:

Very High Hazard Zone

Geologically, this zone is highly unstable and is at a 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 were observed. Besides, it also includes those areas which are located near faults and tectonically weak zones. This zone is manifested on the surface by subsidence of the land as noticed in many parts of Aizawl city. It further includes areas where road cutting and other human activities are actively undertaken. Therefore, the Very High Hazard Zone is found pre-dominantly in settlement areas. This zone is more prevalent in the southern and eastern parts of the district. It constitutes an area of about 375.45 sq. km and forms 10.51% of the total study area. 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.

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) are 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. Vegetation is generally either absent or sparse. The High Hazard Zone is well distributed over the entire study area. It is commonly found to surround the Very High Hazard Zone as seen in many of the villages and towns. This zone occupies 840.13 sq. km which is 23.49% of the total area. The High Hazard Zone is also geologically unstable, and slope failure of any kind may be triggered particularly after heavy rain. As such, allocation and execution of major housing structures and other projects within this zone should be discouraged. Afforestation scheme should be implemented in this zone.

Plate 1. Landslide area at the outskirt of Saitual town

Plate 2. Landslide area at Kulikawn, Aizawl

Moderate Hazard Zone

This zone comprises the areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. It is generally considered stable, as long as its present status is maintained. Although this zone may include areas that have steep slopes [more than 45 degree], the orientation of the rock bed and absence of overlying loose debris and 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 as 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, future land use activity has to be properly planned so as to maintain its present status. This zone covers almost half of the entire study area - about 1504.90 sq. km. which is 42.08 % of the 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 angles are 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 degrees 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. It spreads over an area of about 755.31 sq. km. and occupies 21.12 % of the total study area.

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 extends over an area of about 85.92 sq. km. and forms 2.40% of the total area.

The area statistics of the landslide zones are given in Table 6 and the landslide hazard zonation map is shown in Fig. 6.

Table 6. LHZ statistics of Aizawl district

LHZ Code	Hazard Class	Area [Sq.km]	Percentage
1	Very High	375.45	10.51
2	High	840.13	23.49
3	Moderate	1504.90	42.08
4	Low	755.31	21.12
5	Very Low	85.92	2.40
Other			
1	Water body	14.29	0.40
TOTAL		**3576.00**	**100.00**

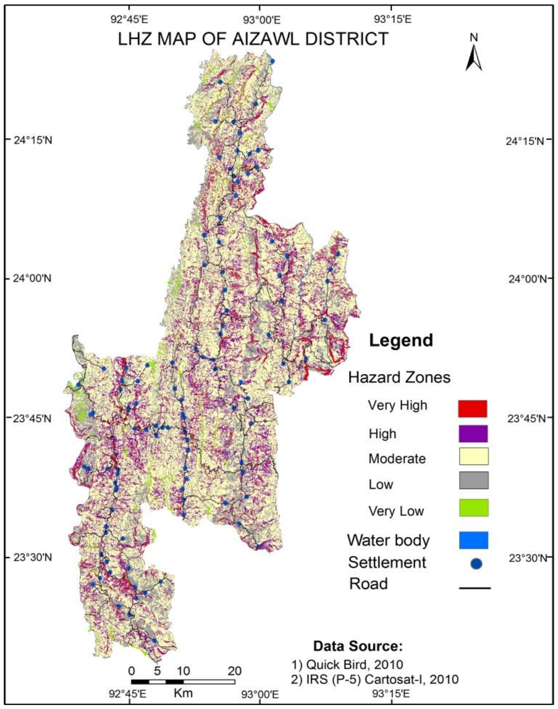

Figure 6. Landslide Hazard Zonation map of Aizawl district

Conclusion

The present study has proven that the advent of remote sensing and GIS techniques with the availability of a wide range of satellite images have greatly facilitated in identification of landslides hazard zones. It is further, proven that Cartosat -I stereo data and IRS (P6) LISS III data together can be utilized for landslide hazard zonation mapping at district level.

Landslide is closely associated with the geo-physical factors like lithology, slope, geological structure and relative relief. It is pertinent to note that landslide activity is mostly confined to the inhabited parts of the district. The intensification of human activities, encroachment on vulnerable land, uncontrolled settlement and rampant expansion of roads are the main causes of landslide within the district. It is, therefore, observed that proper planning is the pre-requisite for settlement expansion, construction of roads and other developmental activities.

Among the natural disasters, landslide can be considered as the biggest challenge while executing the developmental activities in hilly areas. Therefore, landslide hazard zonation is an important scientific exercise for developmental planning in such areas. Hence, the Landslide Hazard Zonation map generated in the present study will form an important data base for selecting suitable sites for developmental activities. It can also be utilized for adopting suitable mitigation measures in the landslide prone areas.

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