www.sciencevision.org

Original Research

Sci Vis Vol 13 Issue No 1
January-March 2013
ISSN (print) 0975-6175
ISSN (online) 2229-6026

Micro-level landslide hazard zonation of Serchhip town, Mizoram, India, using high resolution satellite data

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Received 18 January 2013 | Revised 18 February 2013 | Accepted 22 February 2013

Abstract

Landslide has been one of the major geo-environmental problems in the hilly regions such as Mizoram. It is the most frequent and disruptive natural hazard to which Serchhip town is exposed. Owing to its frequent occurrence, loss of human lives and properties due to landslide are quite common amongst the residents. Although, landslides occur naturally, most of its causes can be attributed to unplanned activities on sites that are susceptible to its occurrence. Such areas are commonly found within the urban complexes where increasing population growth has necessitated the expansion of various infrastructural amenities and constructions are done without proper consideration of site safety and feasibility. Considering the present scenario, this study has been taken up to investigate the landslide hazard zonation (LHZ) of Serchhip town using high resolution satellite data. Various thematic layers, namely, slope morphometry, geological structures like faults and lineaments, lithology, geomorphology and land use/land cover were generated using remote sensing data and geographic information system (GIS). The weightage rating system based on relative importance of various causative factors is used on the different classes of thematic layers. The classes were assigned the corresponding rating value as attribute information in the GIS environment. Each class within a thematic layer was assigned an ordinal rating from 0 to 10. Summation of these attribute value were then multiplied by the corresponding weights to yield the different zones of landslide hazard. A landslide hazard zonation map was prepared showing five different zones which can assist in decision making during the pre-disaster management processes and the development of mitigation strategies.

Key words: GIS; landslide hazard zonation; mitigation; remote sensing.

Introduction

Landslides are short lived and are suddenly occurring natural phenomena. They are just a hazard when they occur in an uninhabited place, however, they turn into a disaster causing extraordinary landscape changes and destruction of life.[1] Though landslide occurs naturally, one of the main causes of landslide in city and town-

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ship can be attributed to human interference. Landslides are amongst the most costly and damaging natural hazards in mountainous regions. The topography of Mizoram is largely 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 of the state are dissected ridges with deep gorges, spurs, keels, etc. Faulting in many areas has produced steep fault scarps.[2] Thus, Mizoram, being a hilly terrain is extremely prone to landslides.

Reports on geology of Mizoram are few due to its isolation and hilly topography. The earliest work on geology of Mizoram was done in 1891 and was reported that the area consisted of great flysch facies of rocks comprising monotonous sequences of shale and sandstone.[3] Studies on Landslide in Serchhip town as well as the whole state of Mizoram are also meager despite the manifold miseries and problems it causes to the public. Few attempts were made to study landslide within the state particularly in Aizawl city. These include geotechnical appraisal of Bawngkawn landslide (1994), examining the causes of the slope failure and suggestions for remedial measures.[4] The possible causes of South Hlimen landslide (1992) which claimed the lives of almost 100 people were also critically examined and suggestions for mitigation measures were made.[5] 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.[6] In view of proposed expansion plan for severely landslide affected Serchhip township, micro-level landslide hazard zonation mapping was carried out. On the basis of sub ranges of total estimated hazard (TEH), the study area has been divided into low hazard zone, moderate hazard zone, high hazard zone and very high hazard zone. Suggestions for expansion of the townships were also given.[7] An in-depth study of slope stability of Serchhip Hmar Veng within Serchhip township was also carried out and it was found that this locality of the town has been severely affected by subsidence and landslides, endangering the lives and property of the people. It was also found that the area comprises very soft shale and interbedded weathered sandstone and siltstone which belongs to the Middle Bhuban Formation of Surma Group of Tertiary age. Remedial measures were also suggested.[8] Geo-data based total estimated landslide hazard zonation at the southern part of the state was also carried out and it was concluded that landslide hazard zonation map is of fundamental importance during planning and implementation of developmental work in hilly state like Mizoram.[9]

The advent of satellite remote sensing technology and geographical information system (GIS) technique has enable us to study landslide phenomena in a more advanced and successful manner. Using the said technique, landslide hazard zonation of Uttaranchal and Himachal Pradesh States had been carried out successfully by the then National Remote Sensing Agency (NRSA).[10] 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.[11] Using high resolution satellite imagery as a base data, landslide hazard zonation mapping of Aizawl city has also been carried out on 1:5,000 scale by Mizoram Remote Sensing Application Centre and the entire area has been mapped into five zones, *viz.* very high, high, moderate, low and very low hazard zones, based on the relative instabilities. Remote sensing and GIS techniques have been proved to be of immense value world-over in hazard zonation, and this has been validated in this study.[12] Keeping all these in mind, in the present study, high resolution satellite data, *viz.* Quick bird and IRS-P5 Carosat-I data were utilised to map the different landslide hazard zones of Serchhip town for undertaking mitigation measures and to identify suitable areas for future development within the township.

MATERIALS AND METHODS

Study area

The study area covers the entire town of Serchhip which is the administrative headquarters of Serchhip district. It is linked by National Highway 54 with Aizawl, the state capital of Mizoram at a distance of 112 km. It is also connected by a metalled road with Lunglei, the headquarters of Lunglei district. Serchhip town is geographically located at the central part of Mizoram between 92°50′ to 92°52′ E longitudes and 23°17′ to 23°24′ N latitudes. Location map of the study area is shown in Figure 1. It falls under Survey of India topo sheet No.84A/15. The total area is 23.92 sq km. The climate of the study area ranges from moist tropical to moist sub-tropical. The entire district is under the direct influence of south west monsoon, with average annual rainfall of 2481.9 mm.[13]

Data used

In the present study, QuickBird satellite data 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 is also used. SOI topographical maps and various ancillary data were also referred to.

Thematic layers

Five thematic layers prepared from satellite data and field work were utilised for this study. They are as follows:

a) 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 five classes, *viz.* heavy vegetation, light vegetation, scrubland, built-up and barren land. The areas covered by heavy vegetation are found to be least suscepti-

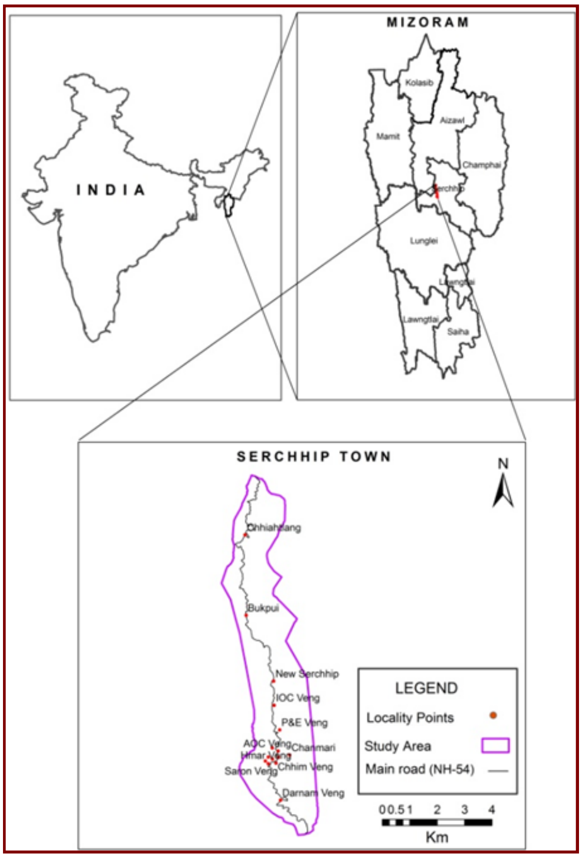

Figure 1. Location Map

ble 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. The statistics of land use/land cover is given in Table 1 and the map is shown in Figure 2.

b) Slope: Slope map was generated using the Indian Remote Sensing Satellite (IRS-P5) stereo-paired Cartosat-I data and Digital Elevation Model (DEM) in a GIS environment. Slope is an important parameter for stability consideration. The hillside slopes are generally steep to very steep, and escarpments are common. The slopes of the area are represented in terms of degrees, and are conveniently divided into eight slope facets, *viz.* 0-15, 15-25, 25-30, 35-40, 40-45, 45-60 and above 60 degrees. As the slope angle

Table 1. Land use/land cover statistics of Serchhip town.

Land use Class	Area (Sq Km)	Percentage
Heavy Vegetation	2.30	9.61
Light Vegetation	13.41	56.06
Scrubland	6.49	27.13
Built Up	1.56	6.54
Barren	0.16	0.67
Total	**23.92**	**100**

Table 2. Slope statistics of Serchhip town.

Degree of Slope	Area (Sq Km.)	Percentage
0-15	2.51	10.51
15-25	0.03	0.11
25-30	0.06	0.25
30-35	1.23	5.13
35-40	3.49	14.61
40-45	7.35	30.72
45-60	6.36	26.59
>60	2.92	12.12
Total	**23.92**	**100.00**

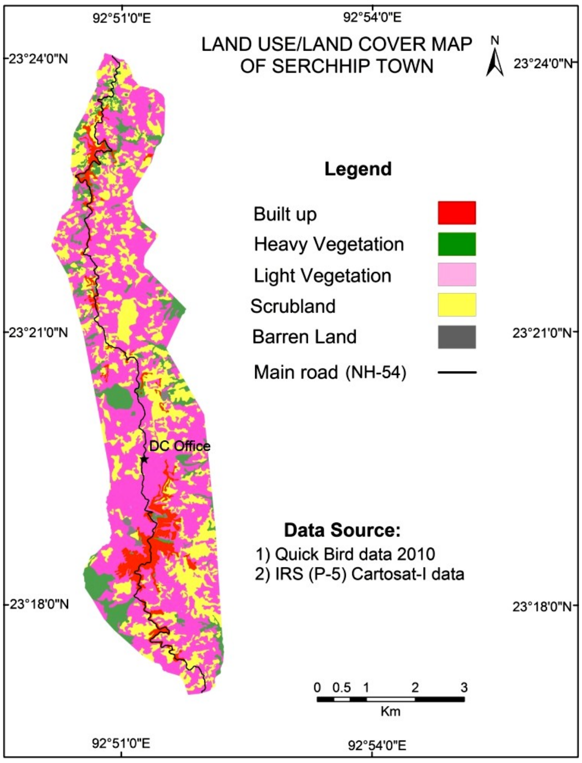

Figure 2. Land use/Land cover map of Serchhip town.

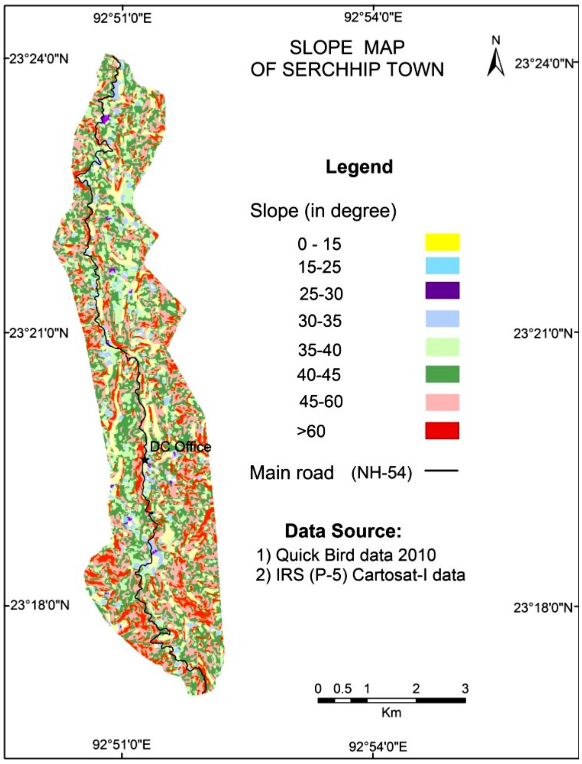

Figure 3. Slope map of Serchhip town.

Table 3. Geomorphological statistics of Serchhip town.

Geomorphic Unit	Area (Sq Km)	Percentage
High Structural Hill	0.21	0.85
Medium Structural	13.26	55.41
Low Structural Hill	10.33	43.16
Valley Fill	0.14	0.58
Total	**23.92**	**100**

Table 4. Lithological statistics of Serchhip town.

Rock Types	Area (Sq Km)	Percentage
Sandstone	12.25	5.21
Shale- Siltstone	7.27	30.41
Siltstone-Shale	14.16	59.20
Crumpled Shale	1.17	4.91
Gravel & Silt	0.06	0.27
Total	**23.92**	**100**

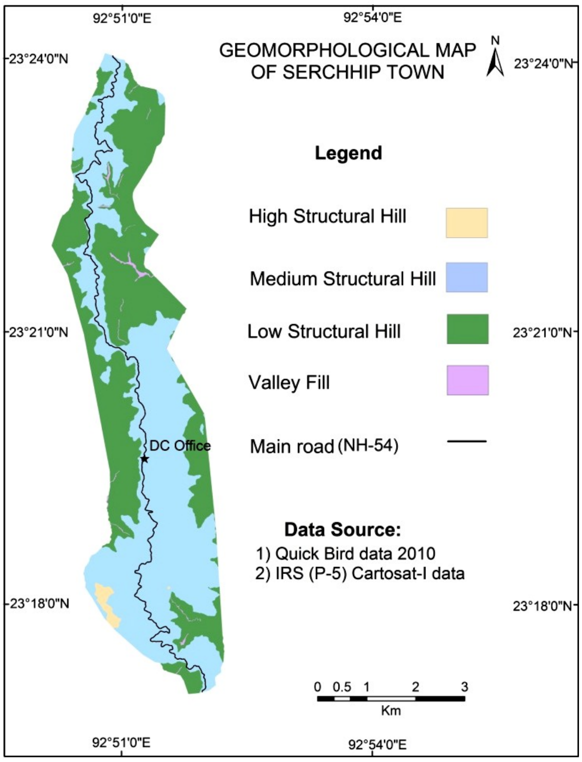

Figure 4. Geomorphological map of Serchhip town.

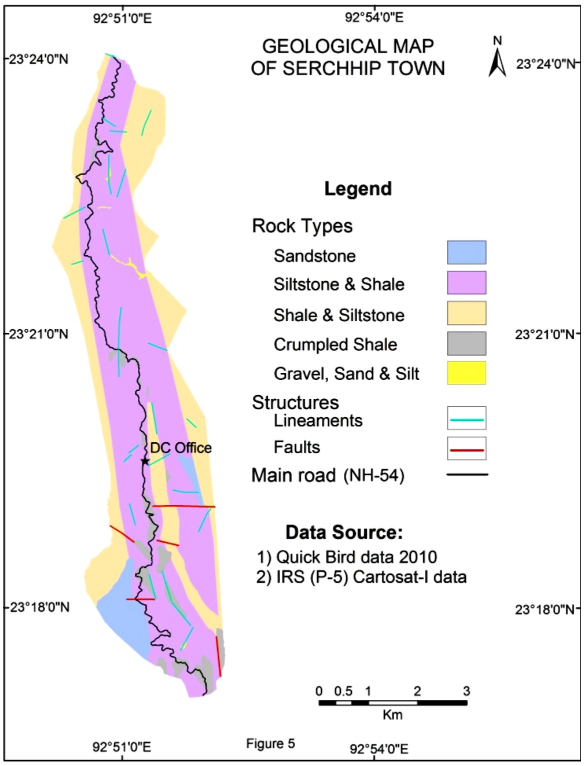

Figure 5. Geological Map of Serchhip town.

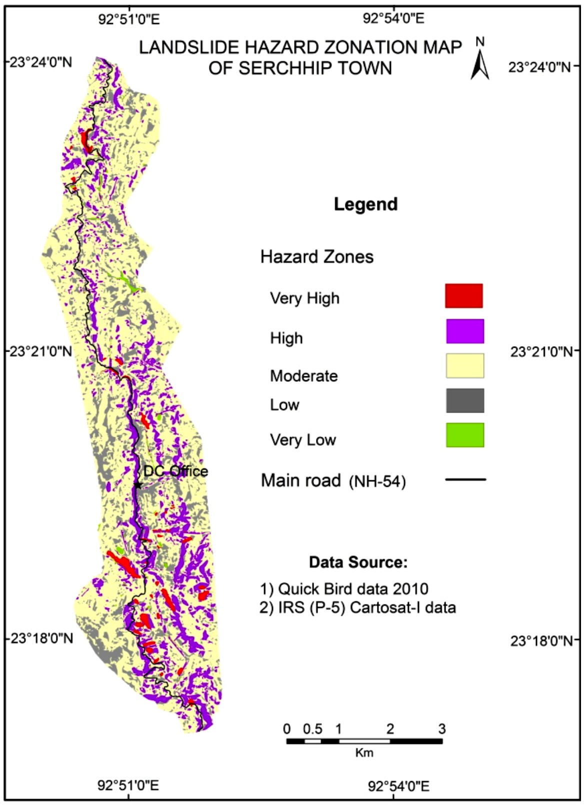

Figure 6. Landslide hazard zonation map of Serchhip town.

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

Parameter	Category	Weight
Lithology	Sandstone	4
	Siltstone & Shale	8
	Shale & Siltstone	9
	Crumpled Shale	10
Land Use/ Land Cover	Heavy Vegetation	3
	Light Vegetation	5
	Scrubland	6
	Barren	7
	Built-up	8
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
Geomorphology	High Structural Hill	4
	Medium Structural Hill	3
	Low Structural Hill	2
	Valley Fill	0

Plate 1. Ground photo of Landslide area at Hmar Veng, Serchhip town.

Plate 2. Quickbird satellite imagery of landslide at Hmar Veng, Serchhip town.

increases, the shear stress in soil or other unconsolidated material generally increases as well.[14] Weightage values are assigned in accordance with the steepness of the slope. The slope statistics of the area is given in Table 2 and slope map is shown in Figure 3.

c) Geomorphology: Serchhip town is situated on a single ridge line which is running in north-south direction. This ridge line lies in between Tuikum river and Mat river which are flowing in northward direction on the eastern and western sides respectively. The ridge line is divided by Kikawn saddle into two almost equal segments. The highest point within the town area is Serchhip tlang with an elevation of 1290 m from the mean sea level. The whole area is divided into high structural hill, medium structural hill, low structural hill and valley fill on the basis of their relative heights with reference to the mean sea level, and nature of the topography.[15] High elevated areas are more susceptible to landslide than areas with lower elevation. Following this pattern, weightage values are given to each of the geomorphology classes. The occurrence of landslide within valley fill has been ruled out. The area coverage of different geomorphological units is given in Table 3 and geomorphological map of the study area is shown in Figure 4.

d) Lithology: The area lies over Middle Bhuban formation which belongs to Bhuban Subgroup of Surma Group of Tertiary age. 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, shale- siltstone unit, siltstone-shale unit, crumpled shale and gravel-silt unit. The crumpled shale unit offers more chance of slope failure than any other units and hence highest weightage value is given. Lithological units comprising shale and siltstone are more susceptible to landslide than the hard and compact sandstone unit. In accordance with this, weightage values are assigned for analysis. The statistics of lithological unit is given in Table 4 and the geological map showing the lithology of the area is shown in Figure 5.

e) Geological Structure: Structurally, Serchhip town forms two limbs of an anticline with approximately N-S trend which is almost symmetric in nature. It has been observed that the rocks exposed within the study area are traversed by several faults and fractures of varying magnitude and length. Areas located within the vicinity of faults zones and other geological structures are more vulnerable to landslides. For analysis, areas with 50 m on both sides of all the lineaments including faults are buffered. The geological map showing the geological structure is given in Figure 5.

Data Analysis

A landslide hazard zonation map based on the integration of data acquired from various geo-environmental thematic databases was prepared. The following geo-environmental factors like slope morphometry, land use/land cover, lithology, geomorphology 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 *a priori* knowledge of the experts. The scheme of giving weightages by NRSA [10] and stability rating as devised by Joyce and Evans [16] has been combined and used in the present study, and is depicted in Table 5.

RESULTS AND DISCUSSION

Combining all the controlling parameters by giving different weightage value for all the themes, the final LHZ map is prepared (Figure 6) 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

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 includes areas where evidence of active or past landslips are observed. Besides, it also includes areas located near faults and tectonically weak zones, which is manifested on the surface by subsidence of the land, as noticed in Hmar Veng area. It further includes areas where road cutting and other human activities are actively undertaken. The very high hazard zone is mainly found within or near the settlement areas, and fall within localities like Farm Veng, part of Darnam Veng, Saron Veng, Chhim Veng, Chanmari, P&E Veng, New Serchhip (along Tlangpui lui). In addition, it is also found near Kikawn, near Kawn Veng field and Sailam field of Chhiahtlang locality. This zone constitutes an area of about 0.44 sq km and forms 1.84% 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. These areas are almost degraded to such a state that it is practically impossible to evolve economically and socially acceptable remedial measures which can positively prevent recurrence of the hazard. Such areas have to be entirely avoided for settlement or other developmental purposes and preferably left out for regeneration of natural vegetation for attainment of natural stability in due course of time.

High hazard zone

It 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. Most of the pre-existing landslide occurrences 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, particularly within the settlement area. It is mainly found to surround the very high hazard zone along the periphery, and is found to cover western side of IOC Veng, P&E Veng and New Serchhip parallel to the national highway. It is also found in some parts of Darnam Veng, Chanmari and Chhiahtlang locality. The high hazard zone is found more prominently in the southern part of the study area. This zone occupies a fairly large area – about 3.81 sq km which is 15.91% of the total area.

The high hazard zone is also geologically unstable area, 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 the vicinity of this zone should be discouraged. If unavoidable circumstances compel the execution of any such activity, due precaution should be taken in consultation with geologists and other experts. It is recommended that a thorough geotechnical investigation of the subsurface geology and hydrogeological condition of the area be suitably made. In addition, afforestation scheme should be implemented in this zone, particularly of those species that help in stabilizing hill slope. Besides, it is also recommended that proper canalization of the streams and improvement of the drainage be suitably undertaken along the streams where toe-erosional activities are maximum. Unless immediate action plans are implemented, this zone will soon deteriorate to the critical situation. Setting up of settlement, as far as possible, is to be avoided and permitted only in localized safe areas.

Moderate hazard zone

This zone is generally considered stable, as long as 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 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. Although this zone is generally considered stable, it may contain some pockets of unstable zones in some areas. Such areas need to be identified by detailed maps and suitable mitigation measures should be taken. Seismic activity and continuous heavy rainfall may also reduce its stability. As such, it is important not to disturb the natural drainage, and at the same time, slope modification should also be avoided as far as possible. 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. This zone is predominantly high in terms of areal extend. It spreads over an area of about 15.57 sq km and occupies 65.10% of the total study area.

Low hazard zone

This include areas where the combination of various controlling parameters is generally unlikely to adversely influence the slope stability. 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, though some areas may not have vegetative cover. Although some of the areas may be covered with soft and unconsolidated sediments, the slope angles are generally low, about 30 degrees or below. 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, and are well distributed within the study area. Areas around Serchhip tlang, Assam Rifles Complex, central part of IOC Veng and New Serchhip fall within this zone. 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. Developmental activities of any kind and allocation of major housing structures may be safely carried out within this zone. This zone extends over an area of about 3.97 sq km and forms 16.58% of the total 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 soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. Since this zone is very limited in area, no major developmental activities can be carried out. This zone covers an area of about 0.14 sq km and forms 0.57% of the total study area.

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

Conclusion

It is observed that human activities coupled with natural factors like lithology, slope, geological structure, rainfall, etc. have made many parts of Serchhip township highly prone to landslides. In this situation, it is necessary to have proper preparatory plans for future developmental activities and it is also necessary to create awareness among the people.

Satellite remote sensing and GIS techniques have been proven to be useful tools for micro landslide hazard zonation mapping using high resolution satellite data. The micro landslide hazard zonation map prepared through this study will be useful for undertaking mitigation measures and also for planning future developmental activities. It will be very helpful for planners, engineers, etc in identifying and delineating unstable hazard-prone areas, selecting viable sites for carrying out developmental schemes and evolving database for the risk analysis of landslides in the area.

ACKNOWLEDGEMENT

The authors are thankful to North Eastern Council (NEC), Shillong, for providing fund for the present study under Disaster Management System Project. The authors are also thankful to other colleagues of MIRSAC, Aizawl, for their cooperation and support during the study.

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