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Identification of Potential Landslide Hazard Zonation Mapping using Geoinformatics for Kohima region, Nagaland, India

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Abstract

Climate change is increasing the frequency of natural hazards such as intense landslide, flood and storms. Predictably, vulnerability assessment focuses on individual risks, but the importance of addressing hazards collectively is now unavoidable using geoinformatics. A huge area of Nagaland is prone to landslides. The main causes of slope instability in the region are attributed to young geology, high slope and relief, heavy rainfall and improper land use practice. In the present study, identification of potential landslide hazard zonation study of Kohima region has been attempted using Google earth's high resolution satellite data. The lithology, geological structures, slope aspect ratio, relative relief and land use and land cover layers of Kohima region were prepared using geoinformatics techniques; which includes geographical information system (GIS), remote sensing (RS) and global positioning system (GPS). These were classified, ranked and weighted according to their assumed or expected importance in causing slope instability based on a priori information of the expert. 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, low hazard, moderate hazard, high hazard and very high hazard.

Keywords: *Landslide, Geoinformatics, Region, Hazard, Slope.*

1. Introduction

The Landslide poses a great economic problem in Kohima region. The soil of Kohima is of sedimentary type with high porosity and highly susceptible to erosion and landslips. The inherent weakness of lithology due to the low compressive strength of siltstone, when exposed to humid climate and heavy rains leads to deep weathering and erosion. Landslide has become one of the most damaging hazards on the earth in recent years [1]. Therefore slope instability is inherent in the region of Kohima. As Kohima region is quite active geologically, landslides and related phenomena occur independently or due to human activities. Given this vulnerability of the city to landslips and slope failures, determination of the causative factors by analyzing the morphology, human activities, land features and their associated terrain parameters assumes great importance. The GoN has accorded a very high priority towards addressing this issue. Accordingly, a landside hazard zonation mapping of Kohima has been carried out and efforts towards the addressable of critical areas, as per the hazard zonation study are underway.

Geologically the area Kohima region is made up of tertiary rocks of Disang and Barail group comprising sandstone and shale. On weathering the shale becomes platy and splintery giving rise to frequent landslides in the area. The entire area is occupied by slope debris material derived from Disang and Barail group of rocks and is highly susceptible to the natural processes of weathering and slope failures. Nagaland forms a part of the northern extension of the Arakan – Yoma range representing some of the cretaceous and tertiary orogenic upheavals forming a fairly young and mobile belt of the earth. The main causes of slope failure in Nagaland 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. Mathur and Evans (1964) gave a detailed account of the stratigraphpy of the northeast in which they also discussed the lithological sequences of Nagaland. The Directorate of Geology and Mining (1978) gave a stratigraphic framework for Nagaland. As Nagaland 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.

The landslides in Kohima region are observed in steep slopes where the runoff from the streams is very high during rainy season. Most of the existing road network has slided due to tremendous landslides, which disrupt the communication of the Kohima region with rest of Northeast India. Almost all creep failure / sliding cases of Kohima region occurs in the rainy season and therefore, can be regarded as rain induced slides. While saturation of soil in general affects the slope stability adversely by increasing the weight and reducing the effective pressure, the percolating water when comes out as return flow also carries the finer fraction of soil, which adversely effects the shear strength parameter. Removal of finer fraction can also lead to gradual formation of piping in the subsurface and result in sudden subsidence. The Kohima region has experienced severe landslides in 1972 and 1995. In 2003 there was an unusual monsoon and as a consequence there were severe landslide and drainage problems.

Kohima region has been experiencing a steady growth in urbanization. Various developmental activities are being taken up within the Kohima 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 regions warrant a detailed study to identify the potential 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 [2].

Literature survey on landslide studies and its geology within Kohima region, in particular are very insufficient. Hiese et., al.[3] have done exhaustive work on LHZ along Kohima town section at 1:50,000 scale, wherein some parts of Kohima region were covered in this study. The geology, slope, relative relief and land use / land cover were studied to generate the identification of potential landslide hazard zonation map of the study area. No other works of this kind have been taken up for Kohima region.

In recent years, with the advent of geoinformatics techniques, potential landslide hazard zonation studies have become more advanced and operative [4]. 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[5], [6]. Apart from several studies, Landslide Hazard Zonation (LHZ) using geoinformatics techniques [7], [8] & [9] have been carried out in Bhagirathi Valley [10], Uttaranchal and Himachal Pradesh [11], Darjeeling Himalaya [12], Sikkim Himalaya [13], Aizawl town [14] & [15], Dikrong river basin [16], Kohima town [4], Kullu District [17], South Sinai, Egypt [18], Giri Valley [19], Nilgiri district [20], Serchhip town [21], Mamit town [22], Saitual town [23], Kolasib town [24] and Aizawl district [25]. It has been proven from the previous studies that satellite data are useful for micro-level landslide hazard zonation in hilly areas.

Observations of all these in mind, identification of potential landslide hazard zonation mapping of Kohima region was taken up for undertaking mitigation measures, and to identify suitable areas for future developmental activities within the region.

2. Materials and Methods

2.1 Study Area

Kohima is located between 94° 4ˈ12.14ˮE to 94˚ 8ˈ56.68ˮE latitudes and 25˚37ˈ26.35ˮN to 25˚45ˈ2.72ˮN longitudes. It has an average elevation of 1261 meters (4137 ft). It is located on the top of a high ridge and the town serpentines all along the top of the surrounding mountain ranges as is typical of most Naga settlements.

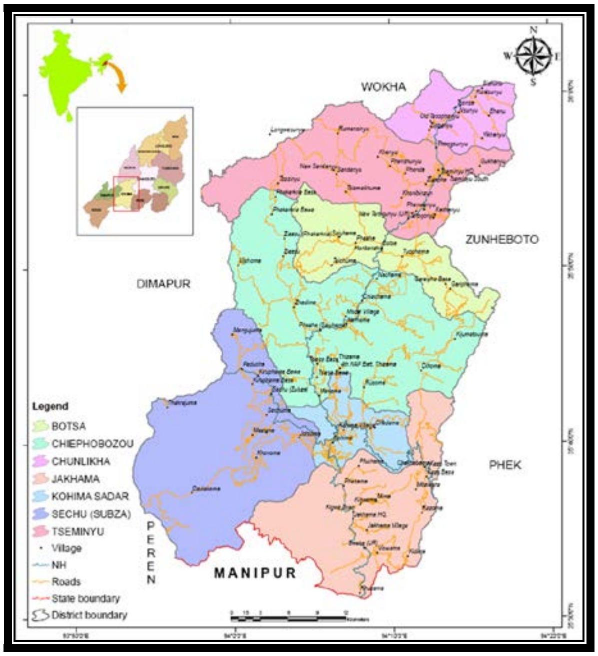

Fig.1: Location map of Kohima region

Kohima, lying at an average altitude of 1500m above mean sea level. Most of this district lies on the Disang group of rocks. A number of Barail outliers are noted forming the high peaks in the district. The terrain represents part of the Intermediate Hills of Nagaland. The Southern portion of this terrain is part of the Kohima synclinorium. Location map of the study area is shown in Fig.1.

2.2 Data Used

Open source Google Earth's satellite imagery having high spatial resolution of 15 m per pixel was used as the main data. Existing line departments satellite data having spatial resolution of 2.5 m was also used to generate aspect ratio map 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. Handheld GPS survey was conducted to verify maps and incorporate relevant information.

2.3 Thematic Layers

The following thematic layers have been prepared using standard geoinformatics technique, and were utilized as parameters for giving weightage and for generating different landslide hazard category.

A. Land Use / Land Cover

Land use / land cover is one of the significant factors that control the occurrence of landslides. The area is dominantly covered with settlement area. It is an indirect warning of stability of hill slopes because it controls the rate of weathering and erosion of the underlying rock formations. The land use and land cover of the study area is classified broadly into six classes (Table I). Among the land use classes, the share of settlement is 66.51% of the total study area constituting about 0.68 km2, which is mostly residential. Patches of scrubs, agriculture (gardens), and degraded vegetation patches are found on the dormant landslide areas and steep slopes. Vegetation occupies about 7% of the total land use followed by an area of 0.049 km2 (4.76%) road coverage. There is also a park (War Cemetery), which occupies about 3% of the area. Table I and Fig. 2 shows the distribution of land use and land cover in different classes in tabulation map respectively.

B. Slope

Slope maps were prepared from the digital elevation model (DEM) and topographic map with the help of contour. The DEM has been utilized to derive the slope map in a geoinformatics technology. Slope is one of the important factors of landslide occurrence. Therefore, slope is one of the most important parameter for stability consideration [26]. Landslides are more common in the steep slope areas than in moderate and low slope areas [10]. The slopes of the area are represented in terms of degrees, and are divided into six slope facets, viz., 0°-15°, 15°-30°, 30°-40°, 40°-50°, 50°-60° and above 60°. 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.

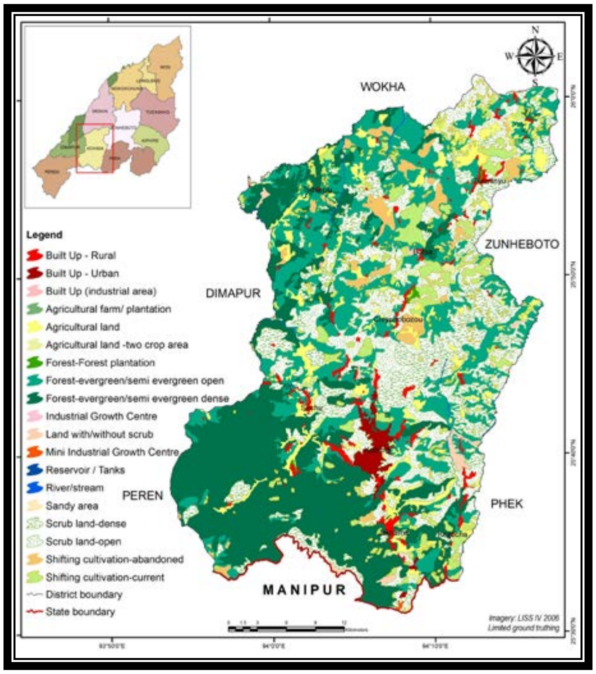

Fig.2: Land use / land cover map of Kohima region

TABLE 1: LAND USE / LAND COVER DETAILS OF KOHIMA REGION

Sl No	***Land use Class***	***Area (m^2)***	***Area (km^2)***	***Percentage***
1	Built up	685972.13	0.686	66.51
2	Mixed (Agri, Veg, Scrub)	184179.92	0.184	17.86
3	Park	32934.32	0.033	3.19
4	Scrub	6247.27	0.006	0.61
5	Vegetation	72967.23	0.073	7.07
6	Road	49090.13	0.049	4.76
Grand Total		**1031391.00**	**1.031**	**100.00**

C. Aspect ratio

Aspect ratio plays a crucial role in the susceptibility of settlements, transport network and land. Hence, it is a significant factor in identification of potential landslide hazard zonation [14]. The study area possesses high relative aspect or local relief aspect and was divided into high, moderate and low classes with elevation ranging from greater than 1000m, 500m to 1000m and less than 500m from mean sea level respectively. High elevated areas are more vulnerable to landslide than areas with lower elevation [21] and following this pattern, weightage values were given to each of the relative aspect ratio classes. The area coverage of different relative aspect ratio classes is given in Table III.

TABLE II: SLOPE DETAILS OF KOHIMA REGION

Degree of Slope	*Area (Km^2.)*	*Area (in %)*
0°-15°	0.402	38.99
15°-30°	0.561	54.41
30°-40°	0.002	0.19
40°-50°	0.031	3.01
50°-60°	0.034	3.30
>60°	0.001	0.10
Grand Total	**1.031**	**100.00**

TABLE III: ASPECT RATIO DETAILS OF KOHIMA REGION

Aspect ratio Unit	*Area (Km^2.)*	*Area (in%)*
High aspect ratio	0.062	6.05
Moderate aspect ratio	0.498	48.30
Low aspect ratio	0.471	45.65
Grand Total	**1.031**	**100**

D. Geology and Geomorphology

The Kohima region is dominated by the presence of tertiary rocks of Disang and Barail series. The Disang series consists of unfossiliferous Sand Stone, Shales, Slates and Phyllites. Due to the splintery character of the Shales, and the softness of the resulting soil, often underlain with a layer of clay, there is frequent occurrence of landslides in the region. The rocks of the Disang series make very steep angles of dip.Most part of the study area is dominated by shales, belonging to the so-called “Disang shale” group. The type of shales found in the study is classified into four major groups have been established for the study area purely based on the exposed rock types of the area, these are named as Black shales, Splintery shales, Shales with sandstone, shales with mudstone. The north-south portion of the middle part of the study area has the concentration of shales with sandstone, where the land is comparatively less prone to landslide. In accordance with this, weightage values are assigned for each of the rock types. The statistics of lithology is given in Table IV and geology map of the study area is shown in Fig. 3.

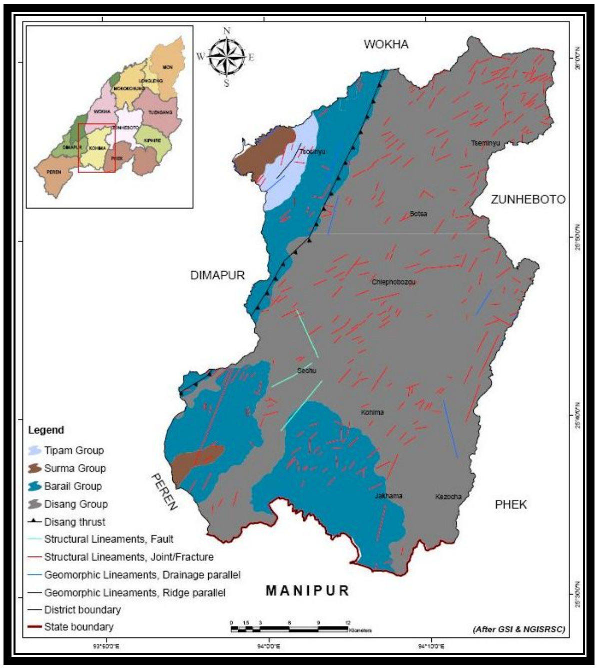

Fig.3: Geology map of Kohima region

TABLE IV: ROCK TYPES OF KOHIMA REGION

Rock Types	*Area (Km^2.)*	*Area (in %)*
Sandstone	0.021	2.02
unfossiliferous Sand Stone	0.501	48.63
Shales	0.477	46.28
Slates	0.021	2.05
Phyllites	0.011	1.02
Grand Total	**1.031**	**100**

The geomorphology map is shown in Fig. 4, the geomorphologic units were extracted from the satellite data (Google Earths data). There are three main Geomorphologic units identified in the area namely, i) Highly dissected hill, ii) Moderately dissected hill and iii) Low dissected hill.

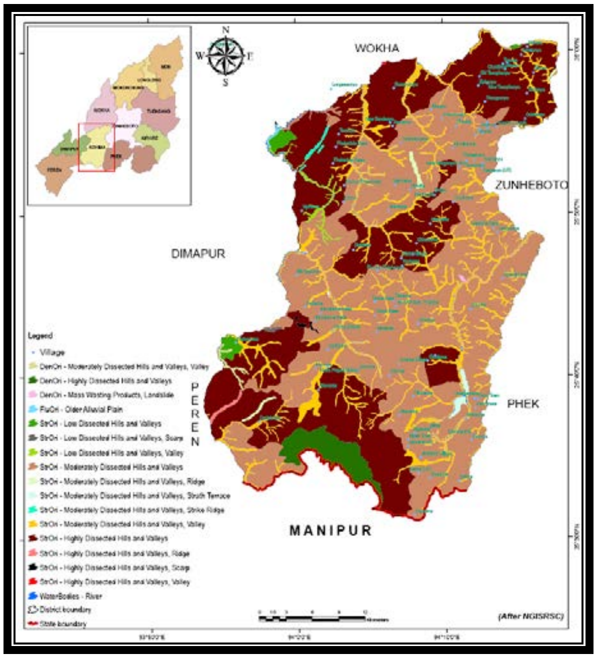

Fig.4: Geomorphology map of Kohima region

E. Lineament and Fault Structure

The area is encountered with a number of lineaments which may be faults, fractures, joints or major shear zones. Structurally, the study area is represented by a NE to SW and NW to SE. The beds generally trend is one major fault along the study area extending from North-West to South-East cutting all across the major rock units. There is also a minor fault towards the south almost parallel to the major fault. 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 geoinformatics technology [27]. Lineaments and faults structures are amongst the most important parameters for identification of potential landslide hazard zonation [28]. Areas located within the vicinity of faults zones and other geological structures are considered more vulnerable to landslides. Fault and lineament map was prepared from the geoinformatics and by referring to the existing geological information, lithological map, and drainage pattern, dissection and field observation. The above Fig. 3 shows the major fault and lineaments in the study area.

3. Methodology and Data Analysis

Identification of potential 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 potential landslide hazard zonation of an area aims at delineating the landslide potential zones and ranking them in order of the degree of hazard from landslides.

The thumb rule method is an indirect method which involves simple ranking and weighting methods for potential landslide hazard zonation that relies on the a priori 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 a priori knowledge of the experts [3]. The first step involves selection of causative factors of slope instability in the area of interest. Consequently, five causative factors viz., geology & geomorphology, lineaments & faults, slope, aspect ratio and land use/land cover were considered in the present study. Each causative factor was converted to a thematic map. Each parameter is carefully analyzed so as to establish its relation to landslide vulnerability. The relative importance of each parameter for landslide is evaluated according to subjective opinion based on the a priori 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 geology & geomorphology layer, the shale-sandstone 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 lineaments and faults 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. 5.

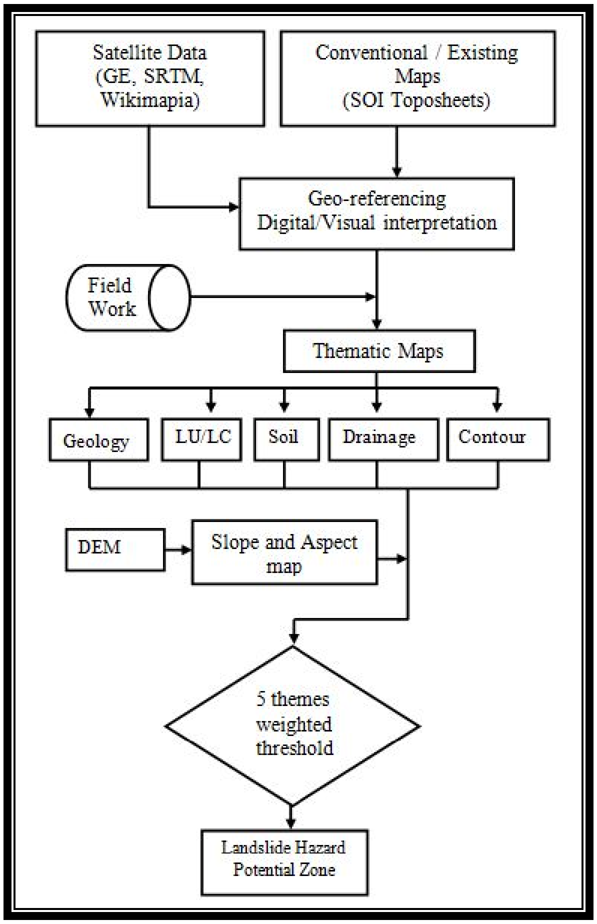

Fig. 5: Research methodology of Kohima region

4. Results and Discussions

Combining all the controlling five themes, and by giving different weightage value for all the category, the final potential landslide hazard zonation map is derived on the scale of 1:5,000. The detailed area of the landslide hazard zones are given in Table VI, and the potential landslide hazard zonation map of the study area is shown in Fig. 6. The study area is classified into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' hazard zones. Various hazard classes are described below:

TABLE V: FIVE THEMES AND ITS RANKING WEIGHT FACTOR OF THEIR INFLUENCE TO LANDSLIDES OF KOHIMA REGION

Parameter	***Rank***	***Category***	***Weight***
Land Use / Land Cover	15	Built up	8
		Mixed (Agri, Veg, Scrub)	6
		Park	3
		Scrub	7
		Vegetation	5
		Road	1
Slope	40	0°-15°	2
		15°-30°	8
		30°-40°	7
		40°-50°	5
		50°-60°	4
		>60°	3
Aspect ratio relief	10	High aspect ratio	5
		Moderate aspect ratio	3
		Low aspect ratio	2
Geology and Geomorphology	20	Sandstone	3
		unfossiliferous Sand Stone	4
		Shales	10
		Slates	9
		Phyllites	7
Lineament and Fault Structure	15	Length of Buffer distance on either side	8

4.1 Very High Hazard Zone

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. The zone is found along Kezekei, New market, AG Road, Area below Para Medical on NH 39, Dak lane area in general. Apart from these, the very high hazard zone is found to be scattered in small pockets at various parts within the Kohima region. It also includes areas where road cutting and other human activities are actively undertaken. 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 0.031 km2 and forms 2.96% of the total study area.

TABLE VI: POTENTIAL LANDSLIDE HAZARD ZONATION OF KOHIMA REGION

Sl. No.	***Hazard type***	***Area in km^2***	***Percentage***
1	Very high hazard	0.031	2.96
2	High hazard	0.093	9.04
3	Moderate hazard	0.130	12.62
4	Low hazard	0.691	67.02
5	Very low hazard	0.086	8.36
Grand Total		**1.031**	**100.00**

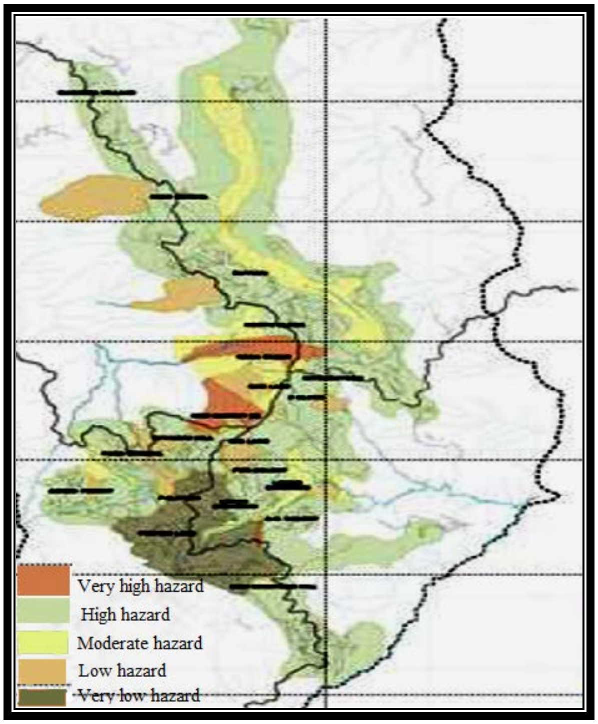

Fig. 5: Potential hazard zonation map of Kohima region

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.

Fig. 6: Landslide prone area of Kohima region

4.2 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 vulnerable 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 Kohima region. It always surrounds the Very High Hazard Zone. This zone is found along Lower AG colony, High school area, Naga hospital, Chota Basti, Well fare Department area, Agri-Forest area, Midland and Lower Chandmari 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 0.093 km2 which is 9.04% 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.

Fig.7: Assam Riffle landslide area of Kohima region

4.3 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 40°), 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 found in Sanou River Bank, Zubharu River Bank, NST Colony, Assam Rifle Camp, Naga Bazaar of the study area. Several parts of the human settlement also come under this zone. This zone covers an area of 0.130 km2 and occupies 12.62% 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.

4.4 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 this zone is found in Secretariat, Lirie, Aradura area, New Police project along the periphery of the study area. This zone covers an area of 0.691km2 and forms 67.02% 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.

4.5 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 0.086 km2, and forms 8.36% 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.

5. 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 Kohima region 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 Google Earths satellite imagery for interpretation and Wikimapia data for DEM and slope generation, supported by detailed GPS locations of the arae can be utilized for producing reliable large scale geological map and potential 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 the Kohima region.

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