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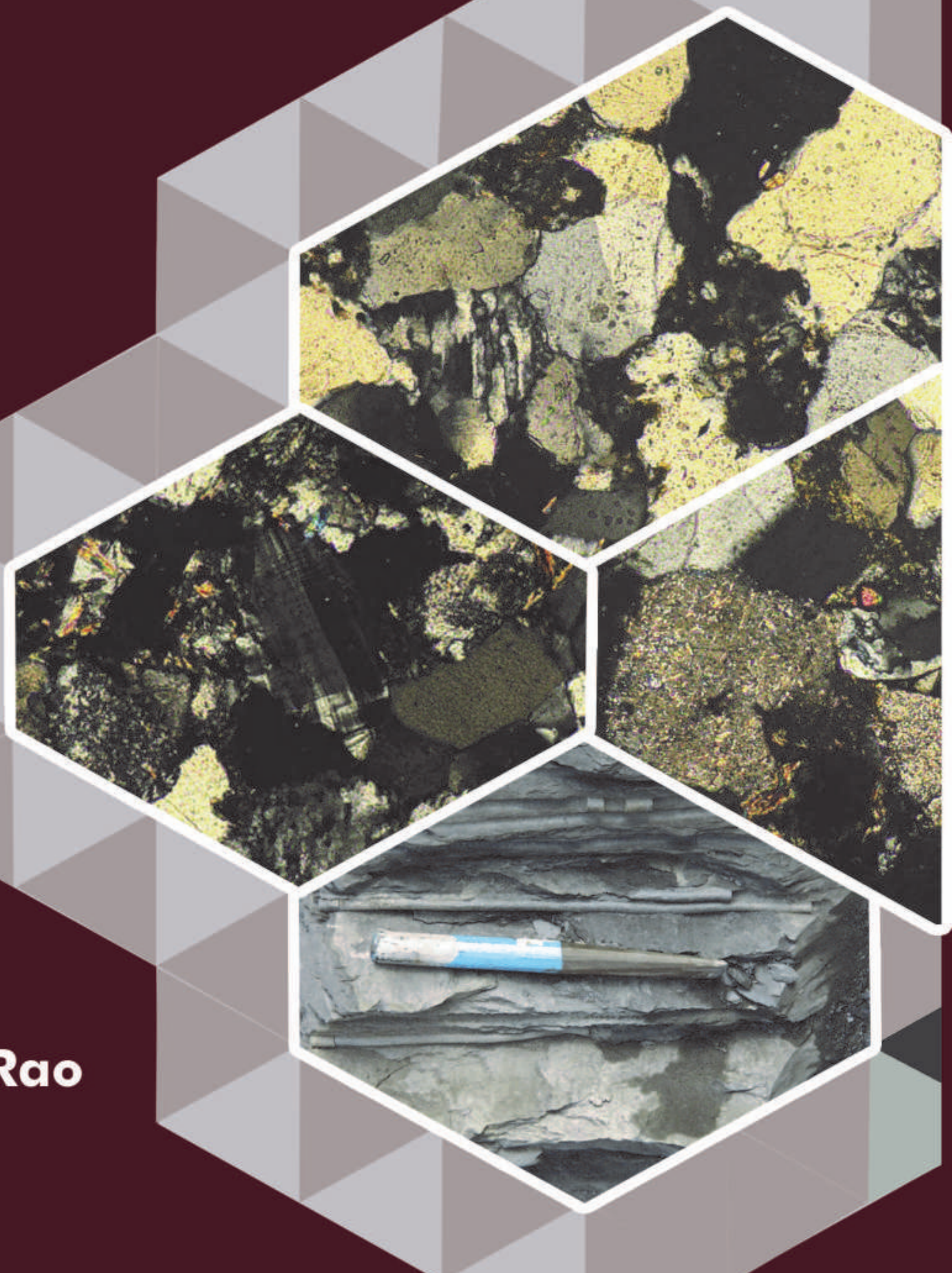

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Terrain Stability Analysis and Susceptibility Mapping Between Kohima and Zhadima, Nagaland

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Abstract

Rapid population growth of Kohima town has necessitated further expansion of the township, which is towards the Zhadima village in the north. The National Highway No. 2 passing through the area is also being widened. Earth cutting for developmental activities has caused much instability in the form of debris slides, mudflows, etc. Hence, a landslide susceptibility map was generated using parameters such as slope, lithology, structure, groundwater, and land use and land cover. Each of these parameters was assigned a suitable rating, with a maximum combined value of 9. The moderately susceptible areas are confined to 4.93 km^2, highly susceptible areas to 6.93 km^2, and very highly susceptible areas to 1.30 km^2 of the study area. The frequencies of landslides (No/km^2) in these three categories are 1.01, 3.17 and 12.31 respectively, indicating that the higher the susceptibility, the greater the chance of slope failure. The low susceptibility areas are not affected by instability.

Keywords: Susceptibility mapping, Kohima-Zhadima, Nagaland

Introduction

Kohima, the capital town of Nagaland is expanding rapidly due to population growth and uncontrolled migration from the surrounding regions of the state. Therefore, the Government of Nagaland has initiated further expansion of the township towards Zhadima in the north. The National Highway (NH) 2 passing through this area is also being widened. Other roads are being carved out in the hills. However, developmental activities are taking place randomly and without any scientific basis leading to slope in stability.

Landslides are downward and outward gravitational displacements of slope-forming materials including rock, soil, artificial fill, etc. due to shear failure. They are intimately related to geo-environmental factors such as topography, lithology, structure, groundwater, land use, vegetation, drainage, and climate. Landslides are responsible for destruction of natural resources and property, disruption of communication and transportation systems, and loss of life. Slope instability including landslides, is common in young terrain, particularly fragile active mountain belts (Aier, 2005; Khalo et al., 2016). Slope modification for developmental purposes and excavation for road widening has a negative impact on slope stability. Instability in the study area includes slumps, debris slides, rockslides, creep, and subsidence, which commonly occur during the monsoon.

To ensure that rapid urbanization and development of hilly areas are not affected by surface instability, it has become necessary to thoroughly analyze and assess the geological factors that promote instability. Such assessments should provide suitable recommendations for mitigation or prevention of landslides. With that in mind, a landslide susceptibility map (LSM) of the study area was generated. Susceptibility mapping was carried out following the guidelines of the Bureau of Indian Standards (BIS, 1998). All factors that have potential to cause landslides were assessed while some were ignored because their role in surface instability in this area was negligible. Those of relative importance, such as slope, lithology, soil cover, structure, groundwater condition, land use / land cover, etc. were used in this study. All surface instability in the area takes place during the monsoon so attempts were made to correlate landslides with rainfall. However, the exact temporal relation could not be derived due to paucity of landslide and rainfall data. The frequencies of landslide incidences were determined by overlaying landslide incidences on the various thematic and susceptibility maps.

Location

The study area, about 13.90 sq km, is located north of Kohima town and includes the Indira Gandhi Stadium in the south, the New High Court Complex and Nagaland University Campus in the East, and the Zhadima junction at the north (Fig. 1). This area is part of the Survey of India (SoI) topographic maps 83 K/1 SW and K/2 NW. It lies between north latitudes 25°41'21.19" and 25°45'57.28" and east longitudes 94°04'14.92" and 94°06'6.50".

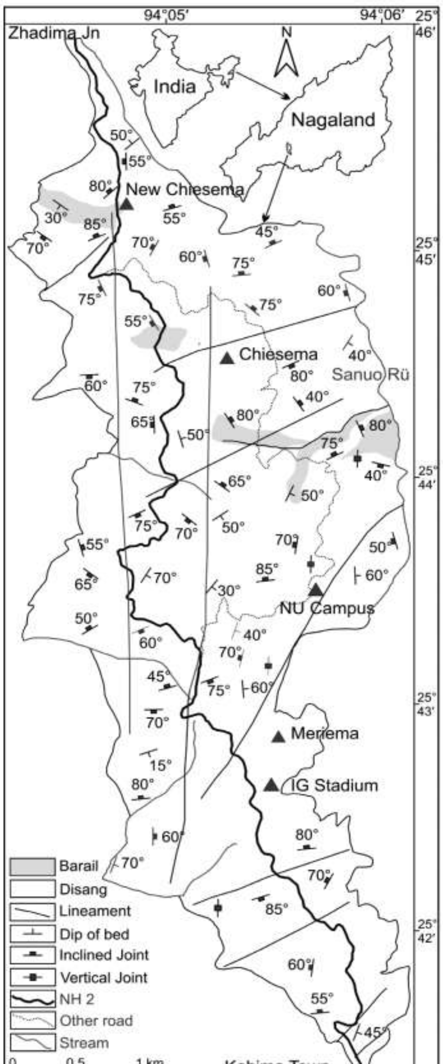

Fig. 1: Geological map of study area

Geological setting

Nagaland is, for the most part hilly, except for the low-lying alluvial tracts bordering the Assam valley. The state comprises more than 90% hill ranges that are made up of a wide array of irregularly distributed ranges, ridges, and spurs. Nagaland is part of a highly dissected mobile belt of the westernmost morphotectonic unit of the Burmese orogen. The eastern margin is part of the Indian Plate that has subducted beneath the Burma microplate (Mitchell and McKerrow, 1975; Verma et al., 1976; Gupta et al., 1984; Mukhopadhyay and Dasgupta, 1988; Ni et al., 1989; Longkumer et al., 2019). This is a tectonically complicated and relatively young immature mountainous terrain. This geodynamically sensitive region is subject to intense tectonism that is responsible for large-scale folding and faulting. Continuing tectonism is responsible for extensive crumpling, jointing, fracturing, and shearing of the rocks. Various geomorphic processes have further weathered and eroded the weakened rocks leading to large scale slope instability.

This part of the region is composed of sediments of the Disang (Upper Cretaceous-Eocene) and Barail (Oligocene) groups. The former are dominantly shales with minor intercalations of sandstone and siltstone while the latter are made up of thick bedded sandstones with minor alternations of thin-bedded shales. The study area is made up of low denuded hills of the Disang Group. Towards the north, the Disang shales are capped by steeper ridges of Barail sandstones. The study area is made up dominantly of shale of the Disang Group. These shales are highly crumpled and partially to completely weathered in many places. Landslides frequently occur in the shale dominated areas. The Barail sandstones make up the ridge crests of this area.

The soil cover in the area, including rock and soil debris, is variable in thickness and range from ~3 to 5 m. Soil exposures are commonly pale brownish to pale gray in colour. They are dark gray, soft, and loamy in areas that are damp and covered by vegetation. The area is rich in outcrops. These outcrops are a result of erosion by streams, landsliding, recent hill-slope widening for roads, etc.

Tectonic disturbances are reflected in the Disang rocks in the form of folds, fractures, joints (Fig. 2), faults, and shearing. Some of the lineaments mapped are of local extent whereas some are regionally extensive. The rocks are affected by three to four sets of joints that generally trend NW-SE, WNW-ESE, and NE-SW. The NE-SW joints indicate the regional trend along which thrusting has taken place. The narrow shear zones noted are continuously affected by instability, particularly during the monsoon.

Fig. 2: Jointed and fractured shale

The area is cut across by numerous streams that dry up during winter. However, some seepage ponds contain water even during the dry season. Parallel and trellis drainage patterns of the streams, indicating structural control, are noted. This region, lying in the North Temperate Zone, receives abundant rainfall during the monsoon. Heavy rainfall and storms are common during the period. The study area comprises small patches of forests, fallow land, and cultivated tracts, besides a few small villages. The cultivated tracts include areas under terrace cultivation for paddy.

Methodology

Susceptibility mapping for this study included topography, lithology, structure, groundwater conditions, and land use and land cover, for which data were generated and thematic maps prepared. Thematic maps on the above factors were superimposed to provide the essential data for the LSM.

SoI topographic maps on 1:25,000 scales were used for mapping. Slope angles were directly calculated from the toposheet. IRS-1D (PAN+LISS III merged) imagery was used for mapping of lineaments. Landslide incidences, including recent and old slides and subsidence in the area were mapped using a GPS. Detailed fieldwork was conducted for determination of lithology, structure, groundwater condition, and land use and land cover. Landslide incidences were plotted on all the thematic maps to get an idea of the role played by each geoenvironmental factor. Landslide incidences were also plotted on the LSM for validation of results.

The study area was divided into a number of facets, which are parts of hill slopes with nearly consistent slope angles and directions. Gullies, stream channels, ridges, spurs, and variations in contour spacing, depending on the topography, were used as boundaries for each facet. Each facet denotes the smallest mappable unit and forms the basis for mapping. Each of the factors taken into consideration for the analyses was assigned a rating. A maximum value of 9 was assigned, as given below.

Contributory Factors	Rating
Slope angle	2.0
Lithology	2.5
Structure	2.0
Groundwater condition	1.0
Land use / land cover	1.5
Total	9.0

Results and discussion

Slope instability processes are products of geomorphological, geological, and hydrological conditions. The modification of these conditions is induced by geodynamic processes, vegetation and land use practices, and the frequency and intensity of precipitation and seismicity (Soeters and Westen, 1996). Climatic condition plays a vital role in slope stability. Landslides frequently occur due to adverse climatologic and geologic conditions in areas of intense tectonic activity (Raj et al., 2011; Supongtemjen, 2013). It is noted that incessant rainfall often acts as a triggering factor for slope failure (Aier et al., 2012). High rainfall may affect natural slopes and disturb slopes differently. Water enters pores and cracks of slope material and causes swelling, which ultimately leads to decrease of shearing strength and development of cracks (Nishida et al., 1979; Crozier, 1989). Such slopes may suddenly lose their stability due to loss of shearing strength, though they may have remained stable for a very long time. Heavily fractured bedrock and varying lithologies can enable an enhanced monsoon rainstorm to trigger large landslides.

Slope angle

Fujita et al. (1976) and Fujita (1980) opine that landslide incidences are closely associated with inclination of slopes. Slopes are generally gentle to moderate, with a tendency to become steeper near valleys, which is common in and around Kohima town (Walling, 2005). Shearing stresses will build up with increase in the inclination of sloping surfaces. Failure will occur when shearing stresses exceed the shearing strength of the slope-forming material. A slope map was prepared on the basis of frequency of occurrence of particular angles of slopes and ratings allotted for each category according to the guidelines of the BIS (1998). This area comprises five categories of slope (Table 1) including very gentle, gentle, moderately steep, steep, and very steep (Fig. 3a). A large number of slopes were mapped as gentle but most of these are locally moderate to steep along stream channels, being areally too small to be categorized as individual facets. Hence, in the overall analyses these slopes are given the ratings of the general slope in that facet. Slides normally occur in areas of locally steep slopes. The frequency of landslides in the very steep slopes is naturally high while that of the steep slopes is also high. The moderately steep slopes also show reasonably high values. The frequency of landslides on the gentle slopes is appreciably low. However, the reason for affecting this category as well by landslides, besides locally steep slopes, is the weak lithology (Supongtemjen, 2013).

Table 1. Frequency of landslide incidences on slope

Slope Angle	**Category**	**Area**		**Landslide**		**Frequency**
		km^2	%	No	%	No/km^2
0° - 15°	Very gentle	1.09	7.84	-	-	-
16° - 25°	Gentle	8.30	59.71	20	46.50	2.41
26° - 35°	Moderately steep	4.08	29.35	19	44.19	4.66
36° - 45°	Steep	0.40	2.88	3	6.98	7.50
> 45°	Very steep	0.03	0.22	1	2.33	33.33

Lithology

Slopes fail due to progressive deterioration of slope material (Zuoan et al., 2006). Mechanical properties of rocks depend on their composition and effect of tectonism and weathering, which greatly reduces their shearing resistance. Lithology greatly influences the occurrence of landslides, because lithological and structural variations often lead to a difference in strength and permeability of rocks and soils. Planes of weakness within rock masses determine the stability of rock slopes to a great extent. The rocks of the study area are classified into seven litho-units (Table 2), and ratings assigned for each category (Fig. 3b), as below.

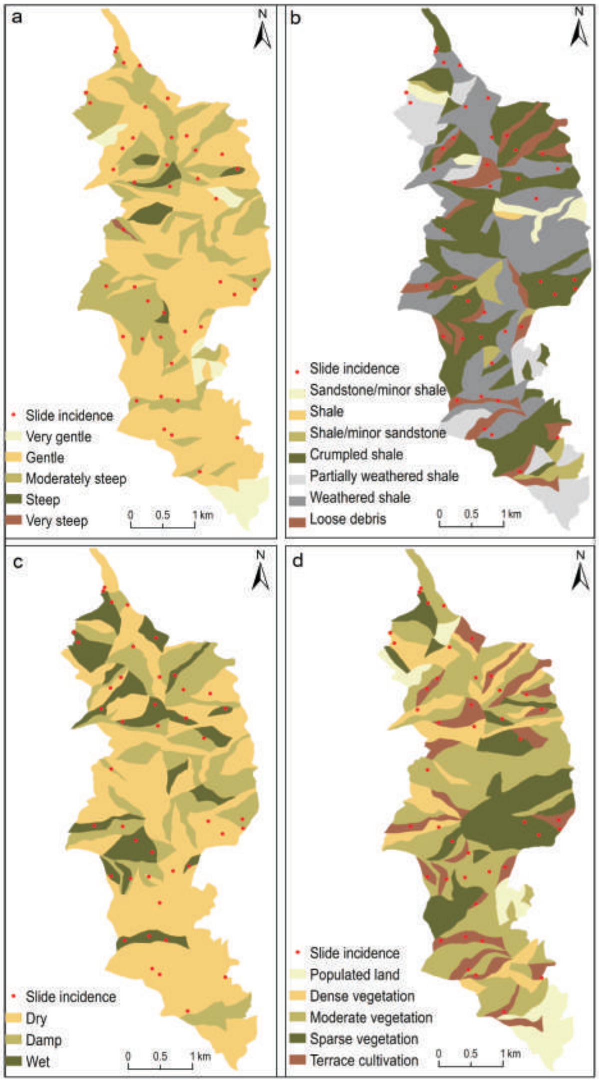

Fig. 3: Thematic maps of study area. a) Slope map; b) Lithological map; c) Groundwater map; d) Land use / land cover map

Litho-units	Value
Sandstone with minor shale	0.5
Shale	1.0
Shale with minor sandstone	1.5
Crumpled shale; partially weathered shale	2.0
Weathered shale; loose debris	2.5

In the study area, surface instability is noted even in gentle slopes. One reason is that facets generally marked as gentle slopes, are locally steep, particularly along stream channels. The major reason for weakness of slopes is the weak rocks and soils that make up the horizons. Hence, it was felt justifiable to give lithology a high rating of 2.5. The frequency of slide distribution indicates that the loose debris areas are most prone to landslides. This is natural as debris slopes, being mixed with clays, possess very low shearing strengths in the presence of water and hence, collapse easily. The moderate frequency of slides in the weathered and crumpled shale horizons is due to the abundance of water from rainfall during the monsoon when the shearing strengths of clays are reduced, besides rampant slope cutting (Fig. 4).

Table 2. Frequency of landslide incidences on lithology

Category	Area		Landslide		Frequency
	km^2	%	No	%	No/km^2
Sandstone/minor shale	0.75	5.40	-	-	-
Shale	0.04	0.29	-	-	-
Shale/minor sandstone	0.26	1.87	-	-	-
Crumpled shale	4.97	35.78	11	25.58	2.21
Partially weathered shale	1.65	11.88	2	4.65	1.21
Weathered shale	4.80	34.56	15	34.88	3.13
Loose debris	1.42	10.22	15	34.88	10.56

Fig. 4: Debris slide due to unscientific road-cutting

Structure

The study area is tectonically disturbed and complicated, which is reflected in the folds, joints, fractures, and faults in the rocks. Geologic and tectonic structures greatly affect the stability of slopes. Structures such as joints, faults, etc. play an important role in the deformation of rocks. However, according to Kandpal and Pant (1995) they are important only if they occur along the slopes or ridges of local topography. The strength of rocks may be reduced due to the presence of bedding planes, joints, or faults. Faults and joints are the most important geological discontinuities that affect slope stability. Increase in moisture content in joints filled with clay can cause considerable swelling pressure which may lead to rockfalls and rock slides. The attitude of bedding or joint planes in relation to slope is an important criterion for determination of slope stability. Anbalagan (1992) gives three relationships based on which ratings were assigned to each facet.

1. Extent of parallelism between the directions of the discontinuity or the line of intersection of two discontinuities and the slope.
2. The steepness of the dip of discontinuity or the plunge of the line of intersection of the two discontinuities.
3. The difference in the dip of the discontinuity or the plunge of the line of intersection of the two discontinuities to the inclination of the slope.

Groundwater condition

The flow pattern of groundwater in hilly terrain is not uniform because it is generally channelled along structural discontinuities in rocks. Hence, an evaluation of the behaviour of groundwater on hill slopes is not possible over large areas. Therefore, in order to make a quick appraisal, the nature of surface indications of the behaviour of groundwater will provide valuable information on the stability of hill slopes (Anbalagan, 1992).

The study area is made up dominantly of shale, much of which are fractured, crumpled, and weathered. Hence, water seepage into the subsurface is high during the monsoon. Water seeps out at various levels along hill slopes during this period. Three categories of groundwater conditions (Table 3) are noted in this area (Fig. 3c) including dry, damp, and wet. Most of the surface area in this study is dry. The frequency of landslides in wet areas is high while damp areas also show relatively higher values compared to the dry areas.

Table 3. Frequency of landslide incidences on groundwater condition

Category	**Area**		**Landslide**		**Frequency**
	km^2	%	No	%	No/km^2
Dry	8.18	58.85	15	34.88	1.83
Damp	3.57	25.68	8	18.60	2.24
Wet	2.15	15.47	20	46.51	9.30

Rainfall

Addition of water on slopes due to rainfall triggers landslides (Jworchan and Nutalaya, 1994). During the early months of the rainy season, higher rainfall intensities are required to activate landslides as compared to the later months. Slopes are more susceptible to landslides when the ground is previously wetted and the water table is high (Supongtemjen, 2013). Abundance of water during the monsoon combines with it to cause debris flows. Intense rainfall is responsible for the rapid growth of pore pressure and loss of apparent cohesion of thin soils, resulting in failure within the soil material or at the contact with the underlying impermeable bedrock. Heavy monsoon downpours account for most of the major landslides in Nagaland. As the study area falls within a small geographic unit, the rainfall event does not vary significantly and thus, the temporal probability is expected to be the same. Storms are common in Nagaland. It has been noted that storms, particularly those occurring well into the rainy season, or those following prolonged wet spells, have been the cause for some of the most damaging landslides in this region (Kemas et al., 2004; Thong et al., 2004; Aier, 2005).

Land use and Land Cover

Rapid urbanization and haphazard developmental activities are the cause of many landslides. Construction of highways without proper scientific studies and planning has also taken its toll in hilly areas. The stability of hill slopes is also directly or indirectly influenced by other land use practices and land cover because these factors control the rate of weathering and erosion of the underlying formations. Land use and land cover of the area have been classified under five categories (Table 4), and map prepared (Fig. 3d) using the following broad classification with values assigned for each category.

Category	Value
Populated land	0.65
Dense vegetation	0.80
Moderate vegetation	1.00
Sparse vegetation	1.20
Terrace cultivation	1.50

The rating for land use and land cover is fixed at 1.5 as the relative effect of this parameter is not as significant as those of slope and lithology. The populated areas made up of small villages are located in geologically more stable areas and as such do not suffer from serious landslide activity. Moreover, indiscriminate earth cutting and unscientific land use practices, such as construction of large and heavy structures, is not resorted to in these villages. Terraced areas under paddy cultivation have been awarded the highest rating. Such areas are confined to old landslides. In these areas, continued water retention for about three to four months during the growing season increases the pore-water pressure tremendously, leading to continued subsidence and/or damage of hill slopes and roads (Fig. 5). The moderately and sparsely vegetated areas are usually geologically weak with unfavorable slopes. Densely vegetated areas are affected by high frequency of landslides, which is ascribed to weak, structurally disturbed rocks.

Table 4. Frequency of landslide incidences on land use and land cover

Category	Area		Landslide		Frequency
	km^2	%	No	%	No/km^2
Populated land	1.18	8.49	-	-	-
Dense vegetation	1.95	14.03	6	13.95	3.08
Moderate vegetation	6.10	43.88	8	18.60	1.31
Sparse vegetation	2.67	19.21	7	16.28	2.62
Terrace cultivation	2.00	14.39	22	51.16	11.00

Fig. 5: Road damaged due to water retention for paddy cultivation

Landslide Susceptibility Mapping

A landslide susceptibility map is a division of land surface into areas, and the relative ranking of these areas according to degree of actual or potential landslides on slopes (BIS, 1998). Ratings for individual causative factors and categories are calculated facet-wise and added up to obtain the total estimated susceptibility. It indicates the facet-wise net probability of instability, with a rating of 9 indicating the maximum value. Landslide susceptibility mapping is the relative ranking of slopes according to degree of actual or potential susceptibility to landslides. The landslide susceptibility map of the study area is generated on the basis of the distribution of the total estimated susceptibility values (Supongtemjen, 2013).

Values	Susceptibility
< 4.50	Low
4.60 - 5.40	Moderate
5.50 - 6.75	High
> 6.75	Very high

The unstable areas of this study include old and recent slides. Subsidences were not mapped as they are confined to narrow shear zones; roads built across these sections, are unstable. The susceptibility map (Fig. 6) delineates the study area into four classes of low, moderate, high, and very high zones (Table 5). The low susceptibility zones are free of landslides. The very high susceptibility zones have a very high frequency, which is followed by the high susceptibility zones. Results indicate that the very high susceptible zones are highly unstable; the high susceptible zones too are unstable. Most of the areas identified as moderately susceptible are more or less stable as long as external factors such as large earthquakes, storms, excessive anthropogenic activity, etc. do not disturb the equilibrium.

Studies suggest that the major triggering factors of landslides in the area are anthropogenic activity and excessive monsoon precipitation. One of the factors for slope destabilization in the terrain is the removal of slope support for widening of roads. Most recent debris slides mapped are along portions of the highway that are being widened. Soil cover in the area permits luxuriant growth of vegetation, but urbanisation and other human activities have disturbed the natural processes thereby exposing the soil to water action, which ultimately results in extensive surface erosion and slope instability. Terrace cultivation for paddy is commonly practiced in old landslide areas rich in silt and clay. In such areas water is impounded in the terraces during the planting season, whereby extreme pore pressure is generated. Such terraces are found in patches along the NH 2. On either side of the highway water logging leads to continuous subsidence and damage of the highway during the monsoon. The area experiences excessive rainfall during the monsoon, which causes abundant percolation of rainwater through the porous soils and highly jointed and fractured rocks. With the high saturation due to excess water the weathered and crumpled shales become unstable leading to mud and debris flows.

Fig. 6: Landslide susceptibility map

Table 5. Frequency of landslide incidences on susceptible zones

Category	Area		Landslides		Frequency
	km^2	%	No	%	No/km^2
Low susceptibility	0.73	5.23	-	-	-
Moderate susceptibility	4.93	35.51	5	11.63	1.01
High susceptibility	6.93	49.88	22	51.16	3.17
Very high susceptibility	1.30	9.38	16	37.21	12.31

Conclusions

The present study attempts to create a landslide database and a susceptibility map based on field studies and using topographical maps and satellite data in a GIS environment. GIS is an effective tool that provides for proper planning and policy and decision-making through data integration and modeling. The susceptibility map generated for this area can serve as a useful management tool. This map gives good indications of stability conditions of the area and clearly defines the various weak zones. The highly susceptible zones need to be avoided for any developmental projects. On this basis landslide management programmes can be planned to check for possible risk to human lives, property, and roads.

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