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Regional Scale Landslide Risk Assessment Using Fuzzy Set Approach: A Case Study on Dhalai District, Tripura

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Abstract: *Assessing the landslide risk using fuzzy set theory and determining the spatial distribution of different risk categories on different landuse/ landcover type is the main focus of the study. For such study, landslide susceptibility map and landuse/ landcover map have been used as input data layers. The input data layers have been quantified by using Analytical Hierarchic Process (AHP) to produce a risk scoring. Finally, these risk scoring maps indicating fuzzy membership values have been integrated to get the final landslide risk scoring map of the Dhalai district, Tripura. The values of landslide risk matrices range from 0.001 to 0.18. The risk scoring map has then been reclassified into very high, high, moderate, low and very low risk zones. The final risk assessment map shows that only 0.45% (10.80 km^2) of the district is under very high risk zone. The major part (94.06%) of the district is under very low and low risk zone. The risk assessment map indicates that, about 50% area of road sections is prone to high or very high landslide risk.*

Introduction

Landslides are the most hazardous phenomena in hilly and mountainous terrain of tropical and subtropical climatic regions. The hilly tracks of Tripura, especially Dhalai district also experience landslides in every monsoon. Most of the landslides are associated with the occurrence of short duration intense rainfall. The other important factors affecting the landslides are bedrock lithology and structure, degree of weathering, slope, relative relief, landuse/ landcover characteristics and hydrologic conditions. Rapid developmental activities like, construction of roads and railway lines through highly rugged terrains have led to the occurrence of this hazardous phenomena in recent decades. Human intervention is also responsible to a great extent and acts as direct or indirect triggering factor together with rainfall. According to the Geological Survey of India report, 0.49 million km^2 or 15% of the land area of this country is vulnerable to landslide hazard. Out of these 0.098 million km^2 is located in north-east region. Large number of landslides has been reported due to intensive rainfall in the month of May and June.

In Mizoram, 17 people died and nine houses collapsed due to massive landslides on 11th May 2013 at Laipuitlang area in northern part of the state capital Aizawl. A large number of villages became inaccessible, 150 houses were badly damaged and the highway was blocked after landslides were triggered by heavy and incessant rains. In Assam, a woman was injured and several houses were damaged due to landslides in different parts of Guwahati following incessant rains the same year. In Nagaland, a large scale landslide (around 80 metres) took place on 15th June, 2013 near the Kisama Naga heritage village in-between Mao (Manipur)-Kohima (Nagaland) sector of NH 29. Due to this landslide vehicular movement on the route was severely affected and prices of essential commodities escalated, disturbing the normal life of Nagaland. In Tripura, 2 people died due to landslides at Simna of West Tripura. Hence, it may be stated that landslide is a major environmental hazard and safety concern for this vulnerable group of people in hilly areas of north-east India is absolutely necessary. But a limited number of researches on landslide have been carried out on in this part of the country (Pandey *et al*., 2008; Singh *et al*., 2011; Phukon *et al*., 2012; Dutta and Sarma, 2013; Lallianthanga *et al*., 2013; Devi and Kushwaha 2013; Singh and Singh, 2013).

Landslide risk assessment is considered as an integral part of landslide hazard management strategy. The identification of risk elements provides the basic platform for assessing the landslide risk of a region. Elements at risk are defined as objects which possess the potential to be adversely affected (Hufschmidt *et al*., 2005). For effective landslide risk assessment, adequate information is needed on the elements at risk.

Till date, only a limited number of researches have been carried out on landslide risk assessment in India. Most of the published literatures on landslide studies are concentrated on landslide inventory mapping, landslide descriptions and qualitative and quantitative hazard zonation mapping (Dahal *et.al*., 2008; Pachauri and Pant, 1992; Mukherjee, 1999; Guzetti *et al*., 1999; Van Westen, 2000; Dai *et al*., 2001; Kosaka, 2000; Sarkar and Kanungo, 2004; Saha, 2005; Van Westen *et al*., 2008; Gupta *et al*., 2008; Negi *et al*., 2012).

Landslide risk is a combination of the probability of occurrence and consequences of such event. Landslide risk assessment on a regional scale leads to delineation of areas with different levels of threat to risk elements. Landslide risk assessment depends on mainly two factors: 1) Landslide hazard and 2) The vulnerability of resources at risk.

Hazard means, the probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area (Varnes, 1984).The probability of landslide occurrences includes both the inherent and the triggering factors. But it is very difficult to get the data pertaining to triggering factors and temporal incidences of landslide, as the triggering factor may change within very short span of time. So, landslide susceptibility concept has been used to determine the probability of landslide occurrences in the present study. Determining landslide risk is usually a complex task as it includes the consideration of exposure of the resource potential (landuse/ landcover) to landslides. To overcome this, hazard level has been taken into account to assess the vulnerability of resources to landslide risk.

The literature survey indicates that there are different qualitative approaches for regional landslide risk assessment. These includes risk registers (Lee, 1999; Lee and Clark, 2000; Lee and Zones, 2004), relative risk scoring (Boggett *et al*., 2000; McDonnell, 2002; Rautela and Lakhera, 2000; Chau *et al*., 2004), risk ranking matrices (Anbalagan and Singh, 1996; Cardinali *et al*., 2002), relative risk rating (Palmer *et* *al*., 2002) and failure modes, effects and critical analysis (Lee and Pradhan, 2006).

The present work aims to assess landslide risk in the hilly areas of Dhalai district by adopting fuzzy logic based approach as a semi-quantitative risk assessment and assess the level of risk of different resource categories.

Regional setting of the study area

The Dhalai district of the state Tripura lies between of 23°25′N to 24°16′N and 91°45′E to 92°10′E with an area of 2,395 km^2. The district is characterised by hill ranges having an almost N-S trend with alternation of narrow river valleys. The important hill ranges are Atharamura, Langtarai and Sakhantlang. Structurally these ranges represent tightly folded strata, developed during the Tertiary period. The maximum height of the hill ranges is 770 m (Fig.1). The height of the hill ranges gradually decreases towards west.

Different types of landforms like structural hills, denudation hill, inter-hill valley, undulating plains, flood plains etc. are found in the study area. The whole study area is mainly composed of weathered sandstone, shale, siltstone and alluvium. Most of the rivers are flowing parallel to sub-parallel with hill ranges with dendritic drainage pattern. The district is drained by the river systems of Dhalai, Manu, Gomati, Khowai and their tributaries which are perennial in nature. These river systems have originated from Atharamura, Longtarai and Sakhantlang hill ranges. In general, drainage pattern is structurally controlled and is in conformity with the topography.

The climate of Dhalai district is mostly warm and humid with moderate temperature. The area receives rainfall mainly from southwest monsoon which commences in the month of May and lasts till September. Storms and thunder showers are common during pre-monsoon season. Average annual rainfall is very high (2,194 mm) in the study area and 70% of total annual rainfall occurs during the monsoon season (between May and September). In general the temperature varies from 20° C to 34° C. Maximum and minimum temperature recorded during the year 2010 is 34.1° C (April) and 9.2° C (January) respectively. The soil texture ranges from sandy clay loam to sandy-loam and are in general, acidic in nature. The pH of the soil ranges from 4.50 to 6.5. About 70% of the total study area is under dense to moderately dense forest cover.

Materials and methods

Regional level landslide risk assessments have been made by using different methods throughout the world. For the present study, concept of fuzzy set theory has been implemented to prepare the landslide risk assessment maps of the study area. Landslide risk assessment by using fuzzy set theory concept requires two input layers i.e. the landslide susceptibility or hazard map and the landuse/ landcover or resource potential map of the area.

To prepare the landslide susceptibility map, eight parameters viz. relative relief, slope, geological formation, distance from fault, drainage density, landuse/ landcover, average annual rainfall and distance from road have been taken into account as landslide causative factors for the present study. The final landslide susceptibility zonation (Fig. 2) has been prepared by integrating all the parameters by using weight-rating method. All the thematic layers were arranged according to their relative importance and weighted numbers (from 1 to 8) were assigned. Similarly, rating was assigned for each class within a layer which is ranging from 0 to 9 by using multi criteria decision techniques in GIS and cumulative score of weight-rating index known as Landslide Susceptibility Index (LSI) was calculated. The resultant map was classified into high, moderate, low and very low susceptibility zones and cross verified by using

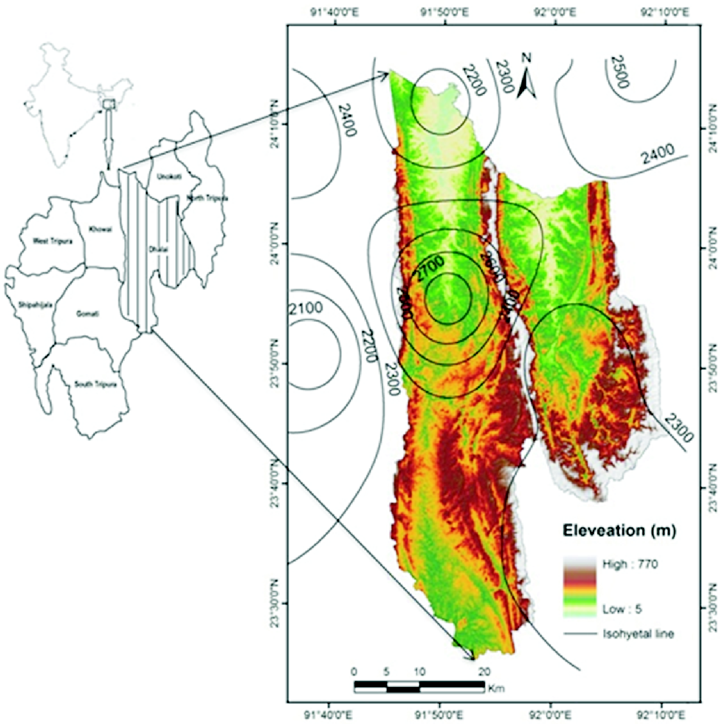

Figure 1. Location : the study area with Digital Elevation Model and Isohyetal line

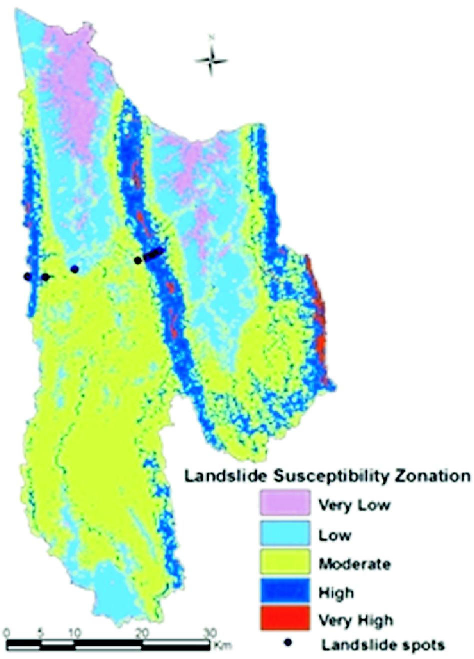

Figure 2. Landslide Susceptibility (Potential) map.

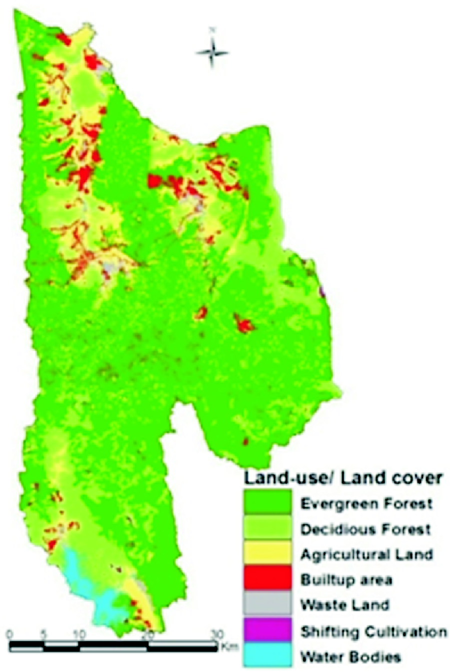

Figure 3. Landuse / landcover (Resource potential) map

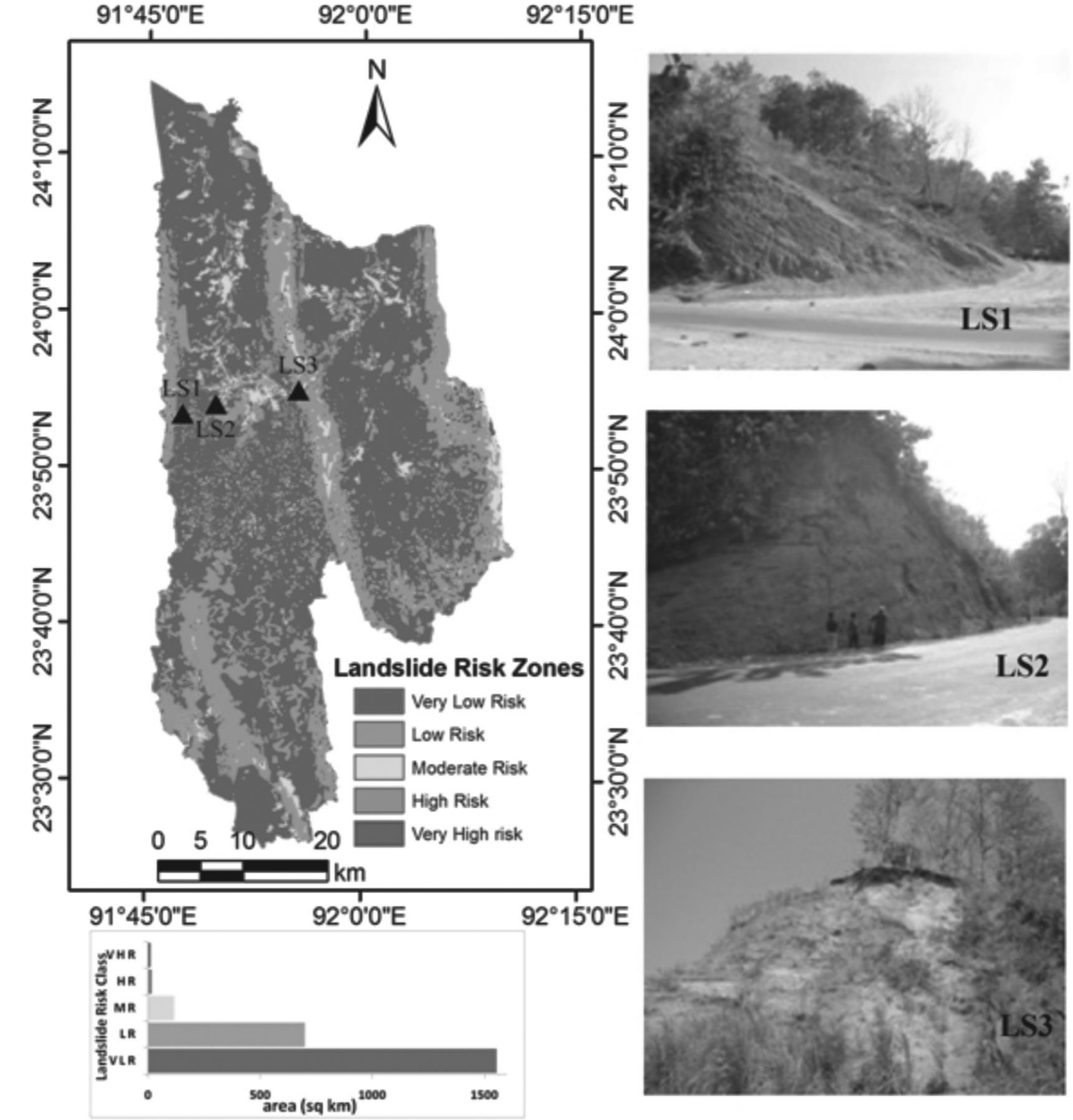

Figure 4. Landslide Risk Assessment Map with three landslide spots: *LS1*: Landslide at 0.5km north of southern district boundary along NH 44 (23°53-08.43 N and 91°46-46.93 E); *LS2*: Earth-fall along the artificial cut slope at 1.5 km north of southern district boundary along both side of NH 44 (23°53-18.43 N and 91°47-20.13 E) and LS3 Earthflow at the crest of the slide at 5 km North from Ambassa town (23°56-22.63 N and 91°54-48.23 E).

recent landslide inventory.

Resource map has been prepared by integrating the landuse/ landcover map with the road network map of the area. The landuse/ landcover map of the study area has been prepared by classifying the IRS- P6 LISS III satellite data along with intensive ground truth verification with the help of GPS.

Fuzzy set theory employs the membership function that expresses the degree of membership with respect to some attributes of interest. The most important aspect of the fuzzy logic-based analysis is the assignment of fuzzy membership values, which must lie in the range of 0 to 1, but there are no practical constraints on the choice of fuzzy membership values. Values are simply chosen to reflect the degree of membership of a set, based on subjective judgment as shown by Bonham-Carter (1994). These values can be user-defined or can be derived from information value (Yin and Yan, 1988) or through Analytical Hierarchical Process (Saaty, 1980). For the present study, Analytical Hierarchical Process has been adopted and fuzzy membership values have been calculated by using pair-wise comparison matrix (Table 1). Fuzzy set theory was first systematically formulated by Zadeh (1965), and it differs from the traditional Boolean set theory in a way that the membership of objects within a set is defined. In classical set theory, an object is either completely member in the set, if it has a membership value of 1 or it is not in the set at all, if the membership value is 0. In fuzzy set theory, membership can take any value between 0 and 1. The values will reflect the degree of certainty of membership.

The landslide susceptibility and resource damage potential have been quantified in terms of fuzzy membership values by using pair-wise comparison matrix and risk scoring. The landslide susceptibility map has been used as an input data layer to quantify landslide potential. Similarly, the landuse/ landcover map combined with a road network map of the area has been considered as resource map to be used as the input layer to quantify the resource damage potential. These two data layers indicating fuzzy membership values have been integrated using raster calculation tool under GIS environment and final risk scoring map was prepared. The final risk assessment map has been prepared depicting various risk zones (i.e. very high, high, moderate, low and very low) by reclassifying the final risk scoring values.

Result and discussion

The landslide susceptibility map shows that very high (1.64%) and high (16.68%) LSI values have been found on the structural hilly areas where landforms are characterised by high relief and comparatively high angle of slope (>25°) and the Bhuban formation (formation under Surma Group of Miocene period). Some very high and high LSI values were also found along the road sections.

Most part of the study area is presently covered with dense forest; occupying more than 61% of the total area and 21.42% area is under deciduous forest. Agricultural land and build up area together covers about 12.59 % of the total study area. 4.6% of area is under shifting cultivation (*jhum*) and wasteland (Fig. 3).

Risk scoring of Landslide Susceptibility Zones (LSZ) map

The landslide susceptibility was reclassified into five zones namely very high (VHS), high (HS), moderate (MS), low (LS), and very low (VLS), which represents various degree of landslide potential (Fig.2). The VHS zone has the highest landslide potential as compared to other and the VLS zone has the least landslide potential. For risk scoring of landslide potential (LP), AHP method has been applied and Eigen vector has been calculated by pair-wise comparison matrix (Table 1). In pair wise comparison matrix, the factor on the vertical

Table 1. Pair-wise comparison matrix of landslide susceptibility (landslide potential) and land use/ land cover (resource potential)

Input layers	Categories	[1]	[2]	[3]	[4]	[5]	[6]	[7]	Eigenvector (fuzzy membership value)
Landslide susceptibility zones	[1] Very high (VHS)	1	3	5	7	9			0.05418741
	[2] High (HS)	1/3	1	3	5	7			0.10526890
	[3] Moderate (MS)	1/5	1/3	1	3	5			0.16766764
	[4] Low (LS)	1/7	1/5	1/3	1	3			0.25933451
	[5] Very Low (VLS)	1/9	1/7	1/5	1/3	1			0.41354155
Landuse/ landcover	[1] Build up area	1	2	3	4	5	5	7	0.35942732
	[2] Shifting cultivation	1/2	1	2	3	4	5	6	0.25656521
	[3] Waste land	1/3	1/2	1	2	3	4	5	0.15274067
	[4] Agricultural land	1/4	1/3	1/2	1	3	4	5	0.09222643
	[5] Deciduous forest	1/5	1/4	1/3	1/3	1	3	4	0.06470923
	[6] Evergreen forest	1/5	1/5	1/4	1/4	1/3	1	2	0.04308909
	[7] Water body	1/7	1/6	1/5	1/4	1/4	1/2	1	0.03124205

axis is more important than the factor on the horizontal axis, this value varies between 1 and 9. Conversely, the value varies between the reciprocals 1/2 and 1/9. Very high susceptibility zone (VHS) was taken in first column, because maximum landslide spots area falling in this zone and the probability of further occurrence is also very high in this zone. The second column compares the high susceptibility zone with the remaining categories. The other categories were compared in the same way as the previous two categories according to their relative importance of landslide occurrence. The calculated Eigen vector values have been considered as fuzzy membership value. Fuzzy membership values representing the landslide potential (LP) based on this AHP method are assigned to each susceptibility zone and are given in Table1.

Risk scoring of resource map

The study area was classified into seven land-use/land-cover categories namely, agricultural land, built-up area, deciduous forest, evergreen forest, shifting cultivation, wasteland and water bodies (Fig. 3). The road networks have been included within the built-up category. These resource categories may be subjected to landslides, which result into resource damages. Generally, built-up area and road section have the highest damage potential, than the categories, like barren land and water. The Analytical Hierarchic Process (AHP) method has been used in order to get fuzzy membership values of different landuse/landcover categories. Based on this AHP method, fuzzy membership values representing the resource damage potential are assigned to each resource category as risk scores of different landuse/ landcover classes (Table 1).

Landslide risk scouring and landslide risk assessment matrix

Landslide potential and resource damage potential were combined in order to get the landslide risk of the present study area. Landslide potential and resource damage potential have been quantified in terms of fuzzy membership values in the form landslide susceptibility (landslide potential) and landuse/ landcover (resource potential) raster data layers. In order to get the level of landslide risk, landslide potential values and resource damage values have been integrated by using the following formula:

$$LRI = LPI * RDPI$$

Where, LRI, LPI, RDPI denotes landslide risk Index, landslide potential Index and resource damage potential Index respectively.

Thus, landslide risk Index values for different combinations of landslide potential and resource damage potential can be

Table 2. Landslide risk assessment matrix for different combinations of landslide susceptibility and resource damage potential

Resource damage Potential (Land use/ Land cover)	Landslide Susceptibility				
	VHS (0.51281)	HS (0.2615)	(MS) (0.12898)	(LS) (0.06338)	(VLS) (0.03334)
Built-up area (0.3594273)	0.184319	0.09399	0.046358	0.022779	0.011982
Road (0.3594273)	0.184319	0.09399	0.046358	0.022779	0.011982
Shifting cultivation (0.25656521)	0.13157	0.067092	0.033091	0.01626	0.008553
Agricultural land (0.09222643)	0.047295	0.024117	0.011895	0.005845	0.003074
Deciduous forest (0.06470923)	0.033184	0.016921	0.008346	0.004101	0.002157
Evergreen forest (0.04308909)	0.022097	0.011268	0.005557	0.002731	0.001436
Water body (0.03124205)	0.016021	0.00817	0.004029	0.00198	0.001041

represented in the form of landslide risk assessment matrix (Table2). The landslide risk assessment matrix shows that all values are ranging from 0.001 to 0.18. The value close to 0.18 indicates high to very high landslide risk potential in categories of built-up area, road and shifting cultivation areas. The values close to 0.001indicates very low landslide risk potential in areas of deciduous forests, evergreen forest and water bodies.

Final risk assessment

The LRI threshold values of 0.09, 0.04, 0.02 and 0.01 were used for categorizing the risk map into five zones, namely very high, high, moderate, low and very low. The respective area under these zones is shown in Figure 4. It is observed from the risk map that only 0.45% (10.80 km^2) of the district is under very high risk zone. The high risk zone accounted for only 0.68% (16.4 km^2) of the study area. The very high and high risk zone is mainly found along the national highway, railway line and in built-up areas of hilly terrains. The forest covered areas of the district are falling under the low to very low risk zones. The very low and low risk zone together accounted for about 94.06% (2252.8 km^2) of the district.

In order to estimate the distribution of different risk zones in various landuse/ landcover categories, the landslide risk assessment map was superimposed on the landuse/ landcover map (Table 3). The result shows that only 242 pixels (0.03% of the study area) of evergreen forest fall under very high risk zone. Most part of the evergreen forest is under very low risk zone (380,232 pixels, 47.78% of the total area) and low risk zone (97,931 pixels, 12.30% of the total area). The agricultural practice of this district is mainly confined within flood plains. Therefore, only 82 pixels (0.01% of the study area) of agricultural area are under high risk category. The road section contains 1869 pixels (0.23% of total area). It is important to mention that out of 1869 pixels, 919 pixels (0.12% of total area) are falling in high to very high risk zones. So, about 50% area of road section is prone to high or very high risk. These high risk road sections are located in Atharamura and Longtarai hilly areas of the district.

Conclusion

Landslide risk assessment is still in its developing stage, and most countries do not have a standardised landslide risk assessment programme. The prepared regional LHZ map serves as the instrumental feature for landslide risk assessment. In the present study, landslide susceptibility and resource maps were integrated to prepare the landslide risk map of Dhalai district in Tripura. Risk prone areas of

Table 3. Spatial distribution of risk zones and resource categories

Riskzone	Number of pixels in different resource categories (% of total area)							
	Evergreen Forest	Agricultural Land	Built-up area	Waste Land	Deciduous Forest	Shifting Cultivation	Road	Water Bodies
VLR	380232 (47.78)	57683 (07.35)	1221 (0.15)	2094 (0.26)	58566 (7.36)	1125 (0.14)	68 (0.01)	15511 (1.95)
LR	97931 (12.30)	11430 (01.44)	7965 (1.00)	4631 (0.58)	109026 (13.7)	837 (0.10)	164 (0.02)	357 (0.05)
MR	9357 (01.18)	911 (0.11)	14064 (1.77)	4181 (0.53)	2931 (0.37)	5886 (0.74)	718 (0.09)	40 (0.00)
HR	164 (0.02)	82 (0.01)	4228 (0.53)	219 (0.02)	165 (0.02)	3 (0.00)	546 (0.07)	11 (0.00)
VHR	242 (0.03)	2 (0.00)	338 (0.04)	7 (0.00)	45 (0.01)	2499 (0.31)	373 (0.05)	(0.00)
Total	487926 (61.28)	70108 (8.81)	27816 (3.5)	11132 (1.40)	170733 (21.45)	10350 (1.3)	1869 (0.23)	15919 (2.00)

the district have been identified and level of risk of all the resource categories have been analysed. For example, about 50% of the existing road sections are under very high to high level of landslide risk. The assessment of risk level helps to take necessary measures to avoid further damages. Although, the information obtained through the present study is not sufficient to minimise the risk directly but it can be used as a basic data to assist slope management, road construction and landuse planning of the region. Finally, it can be concluded that data related to spatial and temporal occurrences of landslide, their characteristics and damages will be more helpful to assess the landslide risk of the region.

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