Landslide Susceptibility Zonation of Tawang District of Arunachal Pradesh using Geospatial Technology

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Abstract

Tawang district of Arunachal Pradesh is geologically fragile and vulnerable in terms of seismicity and topography. The district is plagued by large scale landslides in many parts due to human-induced activities on these fragilities. The present study was undertaken to map the probable landslide susceptible areas of Tawang district using Geographic Information System (GIS). The aspects of geology, seismicity, slope, soil, drainage, elevation, existing landslide locations and the anthropogenic activities were taken into consideration for the study. Weighted overlay multicriteria analysis of GIS was applied to find out the spatial distribution of susceptible areas in terms of landslide. By integrating all the thematic layers with proper weightages and influences, an area of about 144 sq. km of the district is designated as highly susceptible to landslide. Moderate susceptible area is about 27.80 percent while about 65 percent area of the district falls under moderately low and low susceptibility to landslide. The findings of this study regarding the spatial distribution of areas under risk due to landslide could be useful for the management authority for mitigation of landslide hazard.

Key words: *Tawang, GIS, weighted overlay, landslide hazard, susceptibility*

Introduction

The Indian Himalayan and adjoining regions are vulnerable due to natural catastrophic events, namely earthquakes, landslides, flash floods and cloudburst (Sati & Gahalaut, 2013). Landslide is one of the important natural hazards and an active process that contributes to large scale erosion (Pimentel et al., 1995/ Shiferaw & Holden, 1999; Bewket and Sterk, 2002). Different natural phenomena and human disturbances trigger landslides. Natural triggers include meteorological changes, such as intense or prolonged rainfall or snowmelt, and rapid tectonic forcing, such as earthquakes or volcanic eruptions (Guzzetti et al., 2005). Human disturbances include land use changes, deforestation, excavation, changes in the slope profile and agricultural practices in the fragile hilly slopes (Sarma & Barik, 2010). Many landslides occur

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simultaneously when slopes are shaken by an earthquake or over a period of hours or days when failures are triggered by intense rainfall or snow melting (Cruden & Varnes, 1996). These two phenomena are prominent in the eastern Himalayan region (Sarma et al., 2013). Soil erosion triggered by landslide has a range of environmental impacts (Newcombe & MacDonald, 1991) and effective control of soil erosion is a critical component of natural resource management (Pimentel et al., 1995).

For management and control of soil erosion, cause identification and proper delineation of vulnerable sites is pivotal. Geospatial technology could be utilised for identifying the potential areas of soil erosion caused by landslides considering various physical and anthropological aspects of an area. A Geographic Information System (GIS) is well suited for the systematic estimations leading to slope stability evaluation and hazard zonation mapping by handling and analyzing various associated spatial data sets (Boroughs & McDonald, 1998; Baban & Sant, 2004).

Landslide hazard vulnerability study has become a global issue as a consequence of its applied implications (Valentín et al., 2005). The study related to mass movements triggered by landslides has been conducted globally depending on its contribution towards the conservation of ecologically fragile areas (Smith, 2008; Godfrey et al., 2008; Reid et al., 2010). The selection of any appropriate hazard modelling technique is dependent upon the management scale, site-specific conditions and data availability (Carrara et al., 1999). The present context could be related with numerous scientific literatures carried out globally using GIS (Van Westen 1993; Van Westen et al., 2003; Armesto & Martinez, 1978). The spatial data analysis using GIS tools (Issaks & Srivastava 1989/ Rossi et al., 1992; Jackson & Caldwell, 1993) and its consequent advances allow more extensive examinations of spatial analysis (Pastor et al., 1999; Sarma & Barik 2010/ Sarma et al., 2012; Sarma et al., 2013). Global attempts have been made to establish the various methods to predict landslide hazards (Keaton et al., 1988; Lips & Wieczorek, 1990; Coe et al., 2000; Crovelli, 2000; Guzzetti et al., 2002).

Tawang district of Arunachal Pradesh, which is strategically located in the state of Arunachal Pradesh (Figure1), is prone to various natural and man-induced hazards. The fragile geology, seismicity, steep slopes, torrential rainfall and construction of roads and other anthropogenic activities make the district vulnerable to large scale landslides. This is a regular event in the district during the monsoon and post-monsoon seasons, which has plagued the movement of goods and people. The district is cut off with the rest of the world for months due to this human-induced natural phenomenon. In this study, an attempt has been made to identify and map the spatial distribution of different categories of landslide susceptible zones so that proper steps canbe taken by the authorities to check it from more damage.

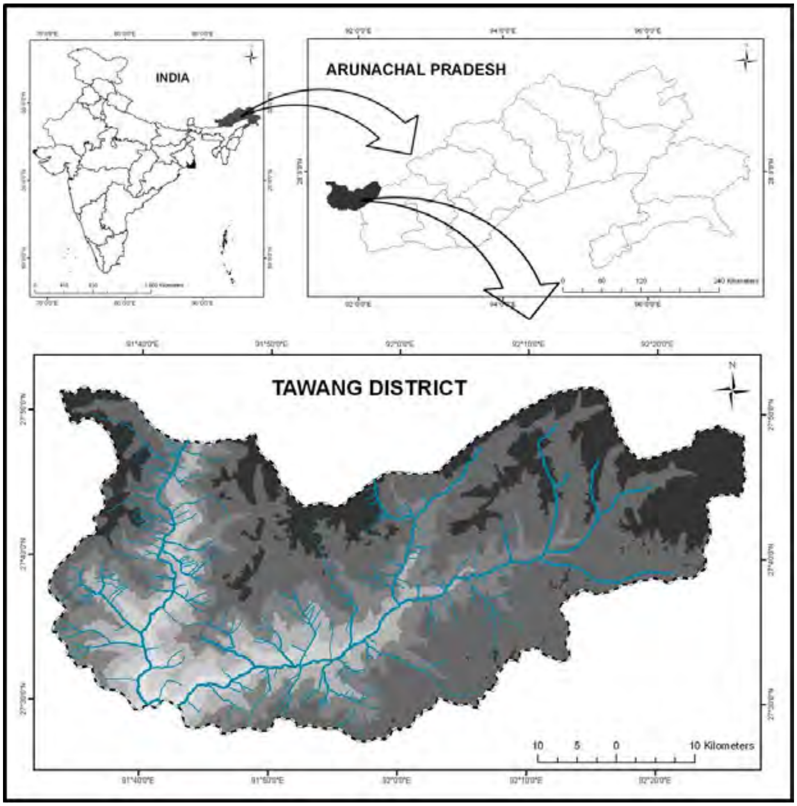

Figure 1: Location of Tawang district of Arunachal Pradesh

Method and Materials

Various thematic features of Tawang district have been delineated on1:50,000 scale using UTM projection system; spheroid and datum used were WGS 84 with UTM zone 46N (Sarma et al., 2012). The soil, geology, river, road and landslide inventory maps were taken from the published maps of State Remote Sensing Application Centre, Department of Science and Technology, Government of Arunachal Pradesh. The image features on the satellite data (Landsat 8, 2014) were interpreted through visual image interpretation to prepare land use/ cover map using the various image elements like tone, texture, pattern, shape, size, shadow, location and association (Garg et al. ,1988/ Lillesand and Kiefer 1987). The relevant Survey of India topographical maps (78M/9, 78M/10, 78M/13, 78M/14, 78M/15, 83A/1, 83A/2, 83A/3, 83A/5, 83A/6, 83A/7 and 83A/8) were utilised for validation of the features prepared. The elevation and slope maps were prepared from the aster DEM data. Intensive field survey was carried out for validation of the results. The GIS and image processing softwares used are ArcGIS 10.1 and Erdas IMAGINE 2014.

Weighted Overlay Analysis

For the preparation of accessibility index the line features like lineaments, river and road and point feature of landslide location were converted into polygon with desired distance from source by delineating multiple buffers. All the thematic polygon features were then converted into raster (Grid) with pixel size of 50m x 50m (Figures 2-12).

Integration of thematic layers was performed using weighted overlay analysis model. Based on the contribution and understanding of the behaviour of different thematic layers, a weightage, which is a qualitative relative measure, has been assigned on a scale of 1 to 9 depending on their overall susceptibility potential level. The influence percentage of each thematic layer has been assigned according to the contribution (Table 1). All the thematic raster features with related item weight and integrated with one another through GIS (ArcInfo spatial analyst environment). As per this analysis, the total weightage of the final integrated grids were derived as sum of the weightage assigned to the different layers based on suitability. In the present study, landslide hazard vulnerability mapping of Tawang district of Arunachal Pradesh has been generated by integration of all above grid layers. The delineation has made by grouping the grids of final integrated layer into five vulnerable zones viz., high, moderately high, moderate, moderately low and low.

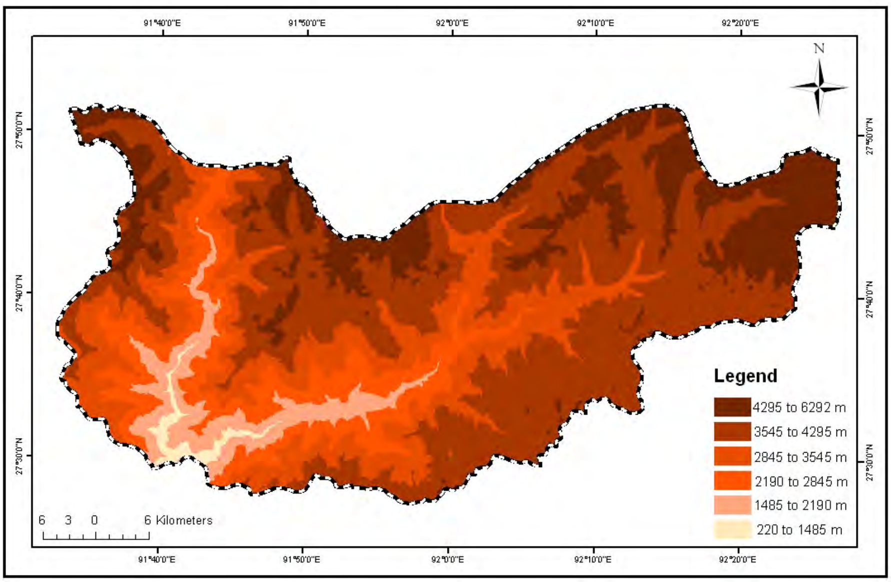

Figure 2: Elevation of Tawang district

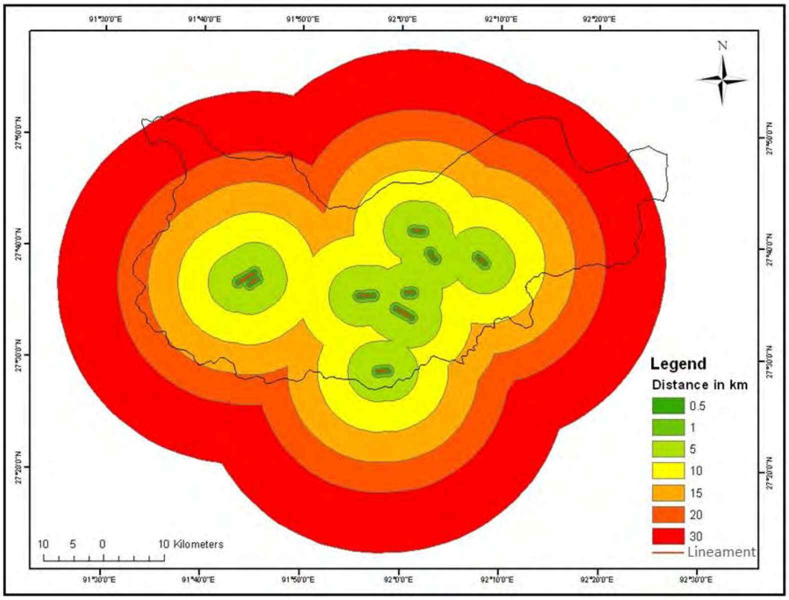

Figure 3: Accessibility of lineaments in Tawang district (Source: State Remote Sensing Application Centre, 2005)

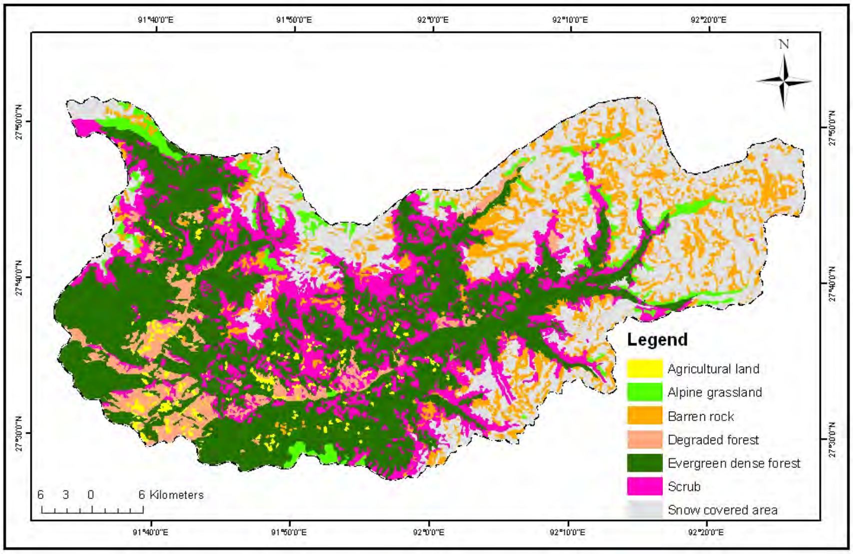

Figure 4: Land use/ cover of Tawang district

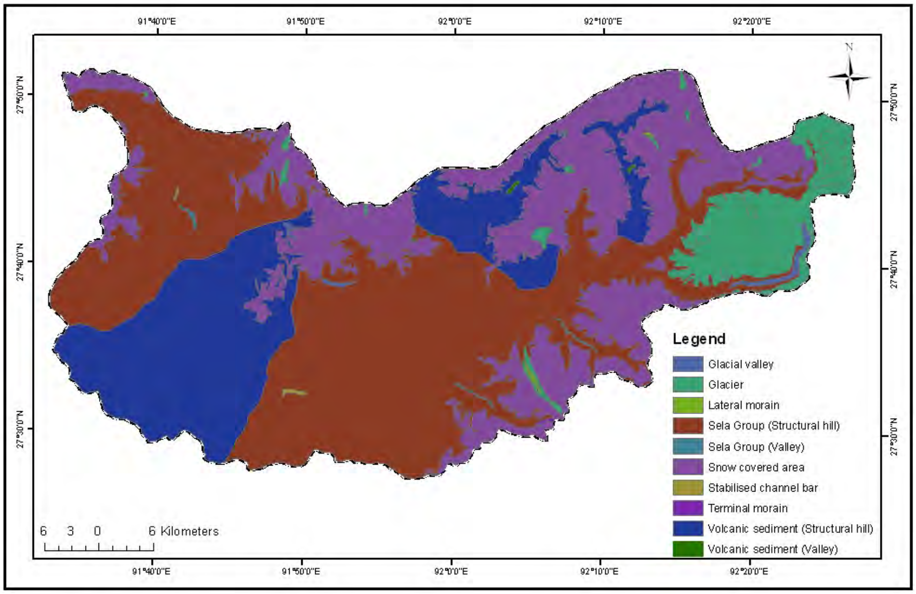

Figure 5: Geology of Tawang district(Source: State Remote Sensing Application Centre, 2005)

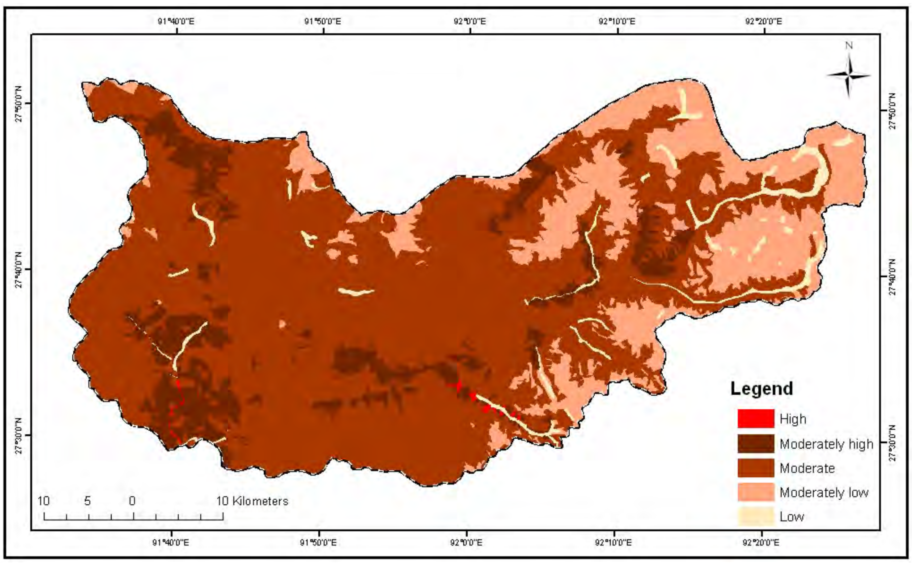

Figure 6: Landslide hazard zonation map of Tawang district(Source: State Remote Sensing Application Centre, 2005)

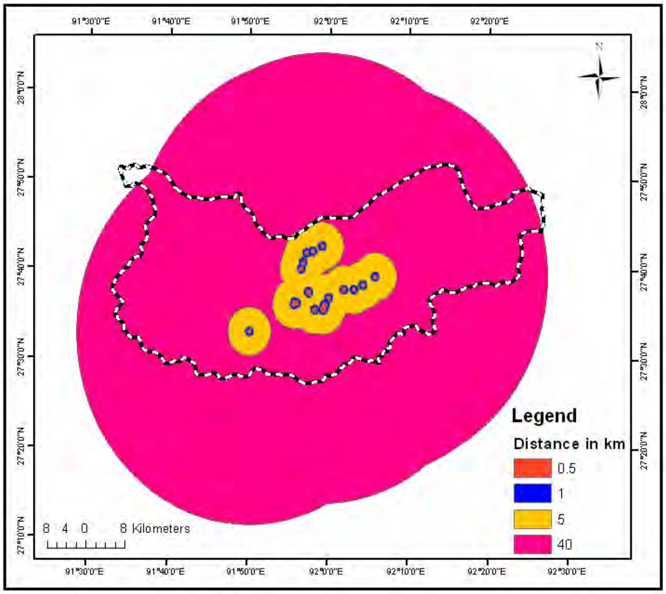

Figure 7: Landslide impact zones of Tawang district (Based on the field data)

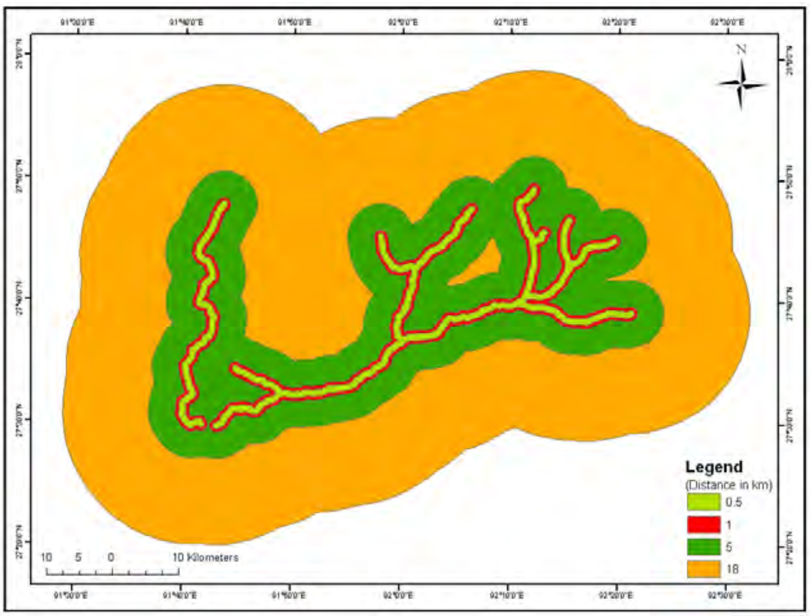

Figure 8: Accessibility of main rivers in Tawang district

Figure 9: Accessibility of tributaries in Tawang district

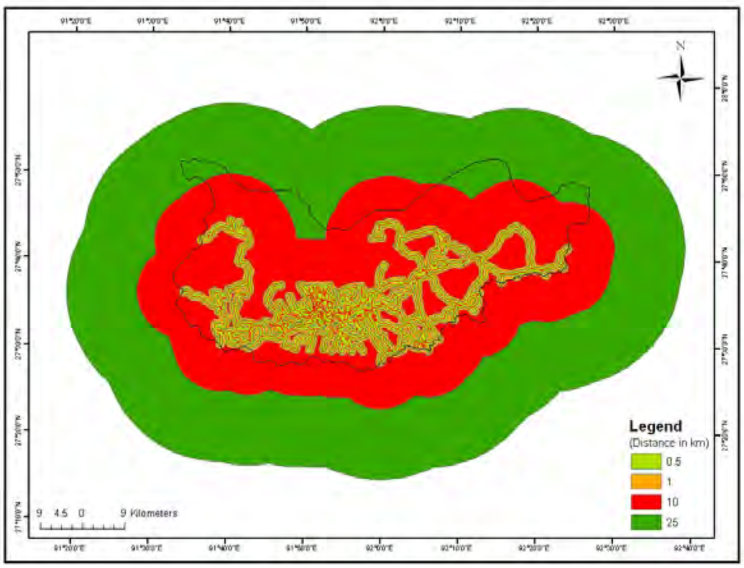

Figure 10: Accessibility of roads in Tawang district

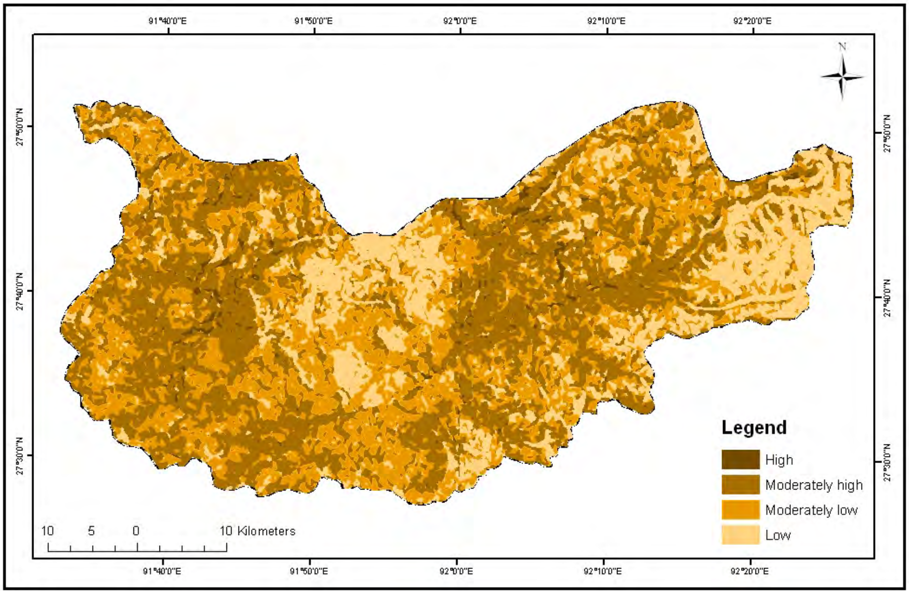

Figure 11: Slope of Tawang district (Refer Table 1)

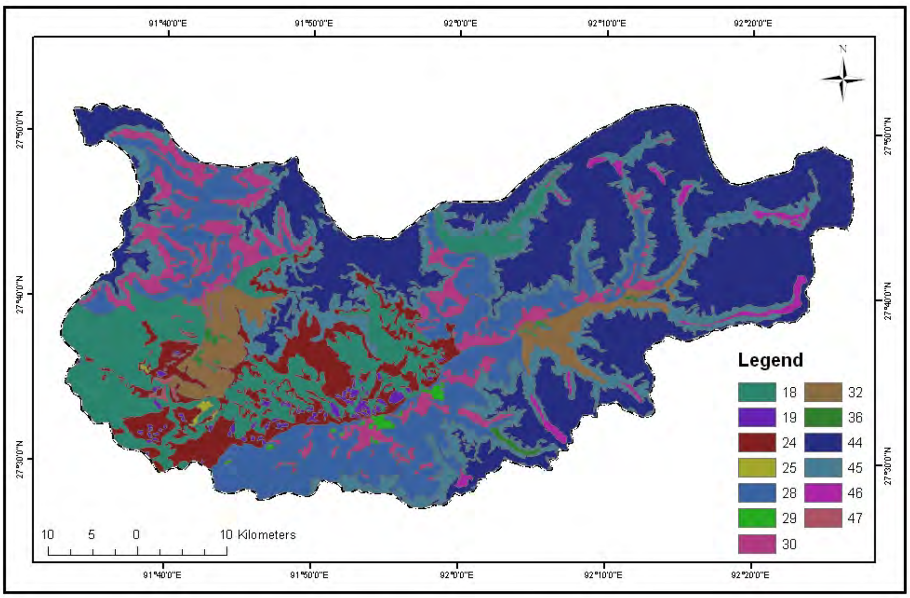

Figure 12: Soils of Tawang district (Refer Table 1)(Source: State Remote Sensing Application Centre, 2005)

(18. Rocky mountain/permanent snow cover; 19. Rocky mountain/seasonal snow cover; 24. Steep slope/tree cover/moderate to severe erosion; 25.Steep slope/scrub/ forest blank/severe erosion; 28. Dense forest/steep slope/slight to moderate erosion; 29. Very steep slope/forest blank/severe erosion; 30. Landslide zone; 32. Forest blank/ very steep slope/severe erosion; 36. Dense forest/steep slope/moderate erosion; 44. No vegetation/jhum land/steep slope/severe erosion; 45. Scrub/jhum land/steep slope/moderate to severe erosion; 46. Scrub/steep slope/severe erosion; and 47. Glacial valley/gravel-pebble-soils brought down by slide of snow).

Table 1: Weighted Overlay Analysis for delineating overall landslide susceptibility of Tawang district, Arunachal Pradesh

Features	Influence (%)	Type	Weightage (1-9)
Elevation	**7**	**Height in m**	
		221-1487	1
		1487-2188	2
		2188-2844	3
		2844-3544	5
		3544-4293	7
		4293-6292	7
Fault	**10**	**Distance in km**	
		0.5	9
		1	9
		5	8
		10	8
		15	4
		20	3
		30	2
Landuse / cover	**9**	**Type**	
		Barren rocky	3
		Snow covered area	2
		Scrub	4
		Dense evergreen forest	2
		Alpine grassland	3
		Degraded forest	8
		Agriculture	8

Geology	**8**	**Type**	
		Snow covered area	7
		Glacier	7
		Sela Group (structural hills)	6
		Glacial valley	4
		Lateral morain	9
		Sela Group (valley)	3
		Volcanic sediment (valley)	1
		Stabilised channel bar	5
		Volcanic sediment (SH)	2
		Terminal morain	6
Landslide hazard zone	**9**	**Type**	
		Moderately low	4
		Moderate	6
		Low	2
		Moderately high	7
		High	8
Landslide location	**12**	**Distance in km**	
		0.5	9
		1	7
		5	4
		40	2
Main river	**8**	**Distance in km**	
		0.5	7
		1	6
		5	4
		18	2
Tributary	**7**	**Distance in km**	
		0.5	6
		1	5
		5	3
		25	2

Road	**7**	**Distance in km**	
		0.5	8
		1	6
		10	3
		25	1
Slope	**12**	**Slope in degree**	
		31 to 44 (Moderately high)	8
		Below 18 (low)	3
		18 to 31 (Moderately low)	5
		44 to 89 (High)	9
Soil	**11**	**Soil characteristics**	
		Rocky mountain / permanent snow cover (18)	1
		Rocky mountain/seasonal snow cover (19)	1
		Steep slope/tree cover/ moderate to severe erosion (24)	4
		Steep slope / scrub / forest blank / severe erosion (25)	6
		Dense forest / steep slope / slight to moderate erosion (28)	3
		Very steep slope / forest blank / severe erosion	7
		Landslide zone (29)	8
		Forest blank / very steep slope / severe erosion (32)	7
		Dense forest / steep slope / moderate erosion (36)	3
		No vegetation / jhum land / steep slope / severe erosion (44)	9
		Scrub / jhum land / steep slope / moderate to severe erosion (45)	8
		Scrub / steep slope / severe erosion (46)	8
		Glacial valley / gravel-pebble-soils brought down by slide of snow (47)	5

Results and Discussion

By utilising the weighted overlay analysis models a map showing different areas of landslide susceptible zones of high, moderately high, moderate, moderately low and low has been prepared (Figure 13 and Table 2). The findings of the study reveals that a considerable portion of the district (6.66 percent) is found to be susceptible for landslide, probably due to maximum anthropogenic influences in terms of slope cutting for road construction, removal of vegetation cover with steeper slopes comprising of loose soil conditions and other geological conditions. All these criteria attribute for delineating the areas susceptible to landslide in already fragile Tawang district.

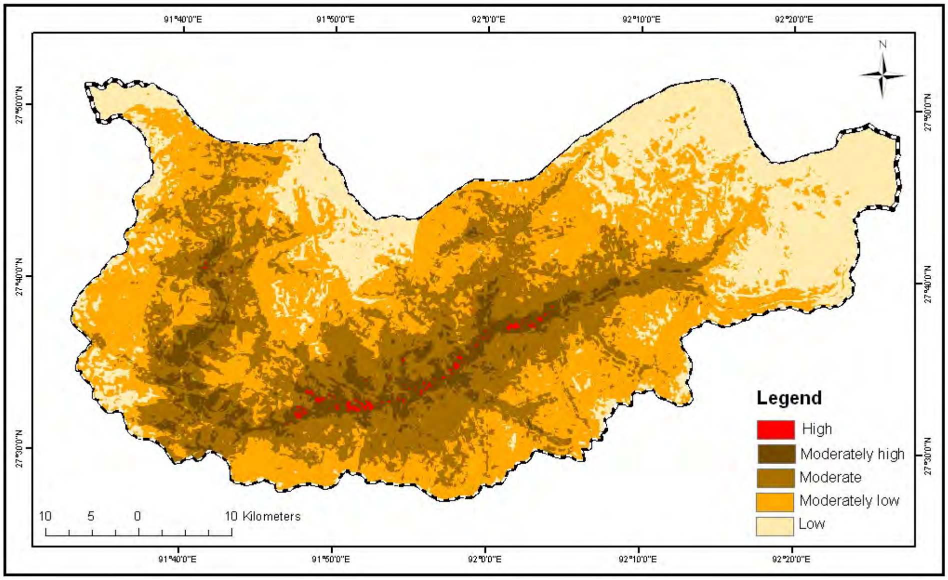

Figure 13: Spatial distributions of landslide vulnerable areas in Tawang district of Arunachal Pradesh

Table 2: Vulnerable areas of Tawang district of Arunachal Pradesh

Vulnerability	Area in sq. km	Percentage
Low	548	25.23
Moderately low	876	40.31
Moderate	604	27.80
Moderately high	138	6.38
High	6	0.28
Total	**2,172**	**100.00**

The large scale soil erosion triggered by landslide is the result of interrelationships among vegetation, topography, drainage, bedrock and soil (Lucía et al., 2010). The present study shows that various geological, topographical and man-induced activities are responsible for making the district vulnerable for landslides (Pimentel et al. 1995/ Shiferaw & Holden 1999/ Bewket & Sterk 2002/ Sarma et al. 2012). Sarma et al. (2012) concluded that the main factors for large scale erosions in northeast India are anthropogenic activities along the fragile hill slopes which are accelerated by torrential rainfall.

Baban & Sant (2005) while studying the susceptibility mapping for the Caribbean island of Tobago using GIS, multi-criteria evaluation techniques with a varied weighted approach found that about 6.4 percent of the total area is under severe risk due to landslide. This finding is in absolute support of the present research. Anbalagan et al. (2008) analysed the relationships of slope morphometry with different aspects like lithology, structure, land use/ cover, and relief. They assigned the maximum impacts where higher slope is free from vegetation cover and with the influence of other anthropogenic activities. Their approach is in agreement with the present study. The findings of this research show that soil erosion rates are influenced by slope, drainage, geology, soil and human induced activities. Besides other factors vulnerability is maximum in the areas where human interferences are more. This study is a point to the findings of Neil & Fogarty (1991); Prove et al. (1995) and Edwards & Zierholz (2001). Similar observations are found by Erskine et al. (2003) and Mahmoudzadeh et al. (2002). The probable vulnerable areas of soil erosion as depicted after the present research is in agreement to these observations.

Conclusions

Being the part of folded Himalayan mountain chain, Tawang district of Arunachal Pradesh is fragile in terms of geology, seismicity and topography. Due to its strategic location, potential for hydroelectric power and tourism, various developmental activities are coming up in recent times and as a result of that large scale landslides are triggered in many parts of the district. Moreover, the region is highly vulnerable to seismic activity which can accelerate the landslides in many parts. This phenomenon has created havoc to the people living downslopes and completely stops the movement of goods and people. The findings of the present study could be utilised to predict the potential areas of landslide hazards and this method could be used in any part of the globe which are prone to this type of natural hazards. The findings of the present research would be useful for the concerned authority to take proper steps for mitigation of landslide hazards.

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