Landslide Risk Assessment for a Part of Coonoor Town, Tamil Nadu

Evangelin Ramani Sujatha*

Abstract

Landslides are off-late a frequent and common hazard in the hill and mountain terrains all over the world. The changing climate pattern with the increase in the number of extreme rainfall events has led to an increase in the frequency of landslides that disrupt the social and economic fabric of these hills and mountain regions. This scenario mandates a thorough analysis of the physical factors causing landslides in a particular geo-environment and the threshold of a triggering factor that initiates the landslide activity. This information can be used to map the spatial propensity of the landslides and the temporal probability of its occurrence which can be expressed as the spatial distribution of hazard in the selected region. A hazard zonation map is a vital tool that can be used to identify the exposure of the region to the hazard. Risk is interpreted by comparing the hazard map and the land use & land cover map. Risk zonation can be used to plan the developmental activities and strategies for mitigation. This is of interest when the region under study has an economy based on tourism. Risk assessment can help suggest alternate economies and optimize tourist infra-structure in a hazard resilient and sustainable fashion.

Keywords: Landslides, Climate Change, Hazard, Risk, Tourist Economy

Introduction

Landslides are geomorphic processes that cause not only considerable to damage to life and property of people in the affected region but also result in severe environmental degradation. Froude and Petley (2018) report that 75 per cent of the landslides reported worldwide between 2004 and 2016 occurred in Asia with India having a considerable share. Geological Survey of India (2016) also report that nearly 12.6 per cent of India's land area is susceptible to landslides, particularly the Himalayan arc and the Western Ghats region. This study attempts to assess the risk exposure of a part of Coonoor town in Nilgiris

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District, Tamil Nadu, falling in the Western Ghats region to landslides. Landslides are one of the most frequent hazards that plague Niligiri District, Tamil Nadu particularly during the north-east monsoon season when copious amounts of rainfall arebeing received. Analysis of physical factors causing landslides, identification of factors triggering landslides in the region and their respective threshold limit to understand the landslide occurrences in the selected area. Literature shows that a number of physical factors like lithology, degree of weathering, slope aspect, slope gradient, curvature, relative relief, soil type, soil thickness, drainage density, distance from drainage lines, proximity to roads and railways, etc. can cause landslides (Pardeshi et al., 2013; Sujatha and Rajamanickam, 2015; Teerarungsigul et al., 2015; Ciampalini et al., 2016; Sujatha 2017). The effect of each physical factor on aiding the occurrence of a landslide is a function of the local geo-environment. Landslide susceptibility map which describes the spatial distribution of the zones susceptible to landslides expresses the cumulative effect of the physical factors contributing to landslides. Several probabilistic, heuristic and deterministic models have been adopted by various authors (Alleotti and Choudhary, 1999; Keefer and Larsen, 2007) to map landslide susceptibility. This map describes only the spatial component of landslide analysis. The temporal aspect of landslide analysis is given by the landslide hazard map which is based on the return period of the threshold of the triggering factor (Jaiswal and van Westen, 2009). Landslides can be triggered by rainfall, seismic activity and anthropogenic activities though rainfall is observed to be the most common triggering factor. Assessing the impact of landslides on the social, economic and environmental components of the region through risk analysis is necessary for the effective town and hazard mitigation planning in the region. Susceptibility, hazard and risk map prepared for the selected area to suggest suitable strategies to minimise the impact of landslides in the region.

Study Area

A part of the Coonoor town (urban area) is selected for the study. It has a total area of 10.55 sq. km. The average temperature of the region is 17°C. The lowest temperatures recorded are in January and the highest in May. The normal rainfall is 1773 mm (Sujatha and Suribabu, 2017). Rainfall is spread throughout the year but maximum rainfall is received in the north-east monsoon season between October and December. The altitude varies between 1520 m and 2105 m above the mean sea level. The climate reflects the altitude of the region. Coonoor town is densely populated with high tourist influx all through the year. Tea cultivation and processing is the largest economic activity in the region followed by tourism.

Materials and Methods

The thematic maps were extracted from ASTER DEM of 30 m × 30 m resolution, Survey of India topographic maps and satellite images. Slope, aspect, curvature, relative relief, land use, type of soil, drainage density, topographic wetness index, proximity to roads and railway lines were used to estimate the susceptibility of the region. Frequency ratio method was used to model landslide susceptibility in the region. Rainfall was observed to the triggering factor in the region. Daily rainfall data and landslide occurrences between 2007 and 2018 were used to identify the threshold limit and estimate the probability of landslide occurrence using Poisson's probability model (Jaiswal and van Westen, 2009). The landslide hazard map was compared with the land use map to assess the risk.

Results and Discussion

Physical Factors Causing Landslides

Past landslide incidences were used to identify factors causing landslides in the region. The landslide dataset was divided into two parts, landslides that occurred before the year 2009 and landslides that occurred 2009 and after. The first dataset was used to build the frequency ratio model and the second dataset was used for validation of the model. Frequency ratio is a simple statistical model that expresses the ratio of the area that has been affected by landslides in a particular class to the ratio of the area of a class to total area. Table 6.1 presents the frequency ratio of the various classes in a thematic layer. Higher frequency ratio indicates the class in a particular theme is more relevant to cause landslide in the given geo-environment.

Table 6.1: Frequency Ratio (FR) of the Thematic Factors

Theme	Class	Frequency Ratio	Theme	Class	Frequency Ratio
Slope (°)	< 5	0.44	Soil Type	Sandy Loam	0
	5-15	1.09		Loamy Sand	1.27
	15-25	1.18		Sandy Clay	5.22
	25-35	0		Clay	0
	>35	0	**Drainage Density (km^2/km)**	Low	1.00
Relative Relief	Low	0.89		Moderate	1.43
	Moderate	1.41		High	0.46
	High	0		Very High	0

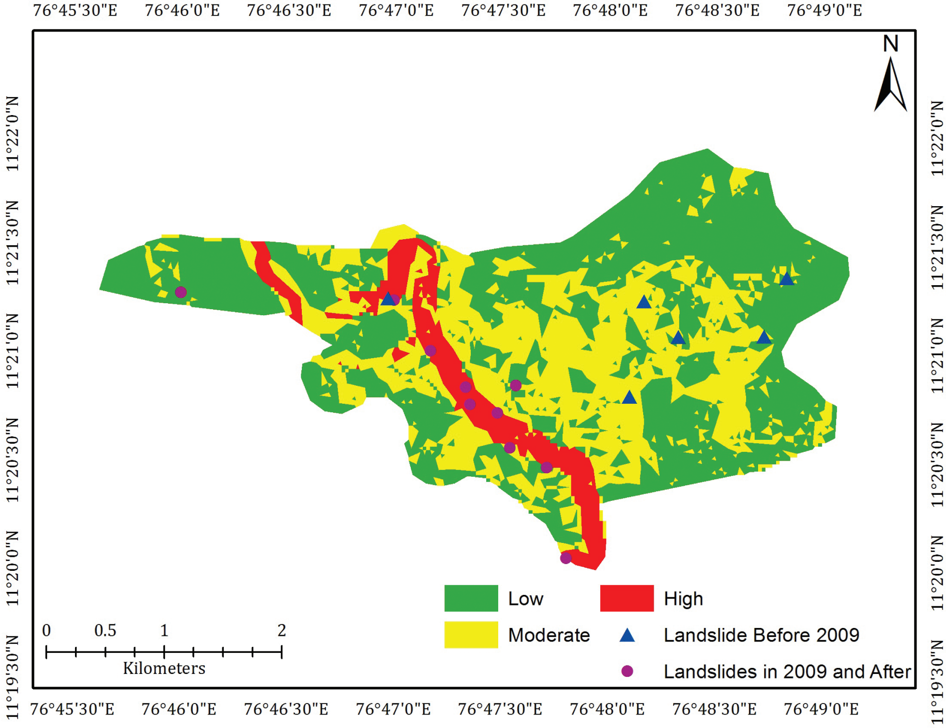
Aspect	Flat	0	**Topographic Wetness Index**	Very Low	0.84
	North	0.20		Low	1.00
	North East	1.39		Moderate	0.98
	East	2.50		High	1.36
	South East	0.62		Very High	0.57
	South West	0.97	**Distance from Railway Lines**	Railway Line	5.19
	West	0.53	**Distance from Roads**	National & State Highway	3.75
	North West	0.31		Major District Road	1.70
Curvature	Convex	1.01		Other District Road	0.05
	Flat	0.96		Village Road	0.76
	Concave	1.01			
Landuse	Forest Plantation	0.13			
	Built-up Land	1.36			
	Agriculture	0.95			
	Forest	0			

The frequency ratio analysis shows that all factors selected for the study are relevant in causing landslides except curvature where landslides are spread almost equally in all classes. It can be observed from Table 6.1 that slopes between 5°-25°, moderate relative relief, east-facing slopes, sandy clay soil, slopes with moderate drainage density and high topographic wetness index, proximity to railway lines and national & state highways are prone to landslides.

Landslide Susceptibility of the Study Area

The frequency ratio is applied as weights to each class in the thematic layers and are combined using ArcMap software. The resulting map gives the spatial distribution of zones susceptible to landslides in the selected area (Fig. 6.1). The railway line and the national highway falls in the high susceptible category. The built-up area also falls both the high and moderate susceptible category.

Fig. 6.1: Landslide Susceptibility Zones in the Study Area



The susceptible zones are classified into low, moderate and high categories and occupy an area 54.4 per cent, 36.9 per cent and 8.7 per cent respectively of the total area. Frequency ratio is calculated for each category with landslide incidences that occurred after 2009 (Table 6.2). The frequency ratio increases with the increase in susceptibility category indicating the good performance of the susceptibility map. Also, Table 6.2 shows that a higher number of landslides are present in the high susceptibility category which has the least area. This again indicates the good performance of the selected model (Can et al., 2005; Sujatha and Rajamanickam, 2015).

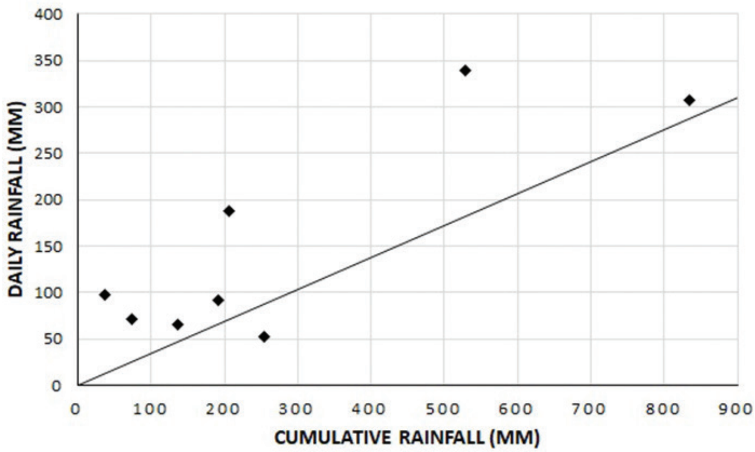
Table 6.2: Frequency Ratio of the Susceptibility Categories

Category	Area Pixels	Landslides Pixels	% Slides	% Area	Frequency Ratio
Low	6383	45	0.168	0.544	0.31
Moderate	4325	82	0.306	0.369	0.83
High	1020	141	0.526	0.087	6.05

Temporal Analysis and Landslide Hazard Zonation

Daily rainfall data and landslide records for the years between 2007 and 2018 were used to determine the rainfall threshold and return period of threshold rainfall. Both single and multiple landslide events were considered as a single event. Daily rainfall and three-day cumulative rainfall was studied to determine the rainfall threshold. Daily rainfall of 70.8 mm was estimated as the minimum rainfall required to initiate a landslide in the study area (Fig. 6.2). This minimum threshold corresponds to the occurrence of small and medium-sized landslides.

Fig. 6.2: Relationship between Daily Rainfall, Cumulative Rainfall and Landslides



Gumbel's distribution was used to determine the return period of threshold rainfall. The return period of threshold rainfall was 1.37 years. Major landslide events recorded in November 2009 showed that the daily rainfall required to initiate them was around 188 mm and a three-day cumulative rainfall of 206 mm and above was required to trigger landslides of huge volume. In the year 1979 and 1993 such extreme rainfall events caused multiple large landslide events in the study area and the daily rainfall recorded during these events were 177 mm and 310 mm, respectively. Based on these observations, it can be said that major landslides occur when a daily rainfall of more that 180 mm is experienced. Poisson's probability was used to determine the probability of occurrence of a landslide when the threshold is exceeded. Daily rainfall exceeded the threshold rainfall 45 times in the study period and 17 landslides occurred when the rainfall exceeded the threshold rainfall in the same period. The probability of a landslide occurring when the threshold is exceeded is nearly 36 percent.

Risk Analysis

Risk is the exposure to hazard and is a function of the damage potential (Anbalagan and Singh, 1996). Risk analysis can help in improving the resilience to risk of the area affected by landslides. A comparison of the landslide hazard zones with the land use map shows linear infra-structure like railway lines & highways and built-up area is most affected by landslides. Also, the damage potential is high for these categories. The number of landslides has increased over the period of investigated time. Anthropogenic activities have led to an increase in landslides. Increase in the density of the built-up area has increased the risk to landslides. Also, slope modification for regular maintenance along the railway lines and widening of roads have contributed to an increase in the number of landslides.

Conclusion

Landslides have emerged as a major natural hazard in the selected region in recent years. The changing climate regime with a number of extreme rainfall events warrants a thorough analysis of the physical and triggering factors causing landslides. Local thresholds are more contributive to the design of early warning systems and this study will be a step forward in this direction. Risk assessment can help combat the losses due to landslides and help in building a community more resilient to the risk of landslides. The economy of the region is largely based on tourism and related activities mandating a thorough risk assessment. The regions more prone to risk here are the slopes along the railway lines & major roads and the built-up areas. Slope protection works along the slopes like retaining walls and breast-walls have provided. Hence, turfing the slopes with plants like vetiver grass and asparagus can help improve the stability of the slopes. Also, regular maintenance of the drainage outlets can help in slope protection.

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