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Probabilistic landslide susceptibility mapping along Tipri to Ghuttu highway corridor, Garhwal Himalaya (India)

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ABSTRACT

Landslides are very crucial natural hazard that pose serious threats to lives and livelihood in the Garhwal Himalaya, particularly during the monsoon season. The aim of this study was analysis of distribution probability of landslides along the highway corridors and susceptibility mapping. Hence, a comprehensive landslide inventory has been prepared using Landsat 8 satellite images for 2009, IRS LISS-IV MX satellite image for 2011; and Google earth images for 2014. In order to validate the landslide locations, repeated field investigations were carried out along the road corridors in the area. It has been analyzed that approximately 76% of the landslides have occurred along the highway corridors and streams in the study area during the monsoon season (July to September). The factors which cause landslides; such as relative relief, slope, slope curvature, aspect, geology, soil, surface dissection, compound topographic wetness index (CTI), normalized difference vegetation index (NDVI), land use, distance to stream and distance to road were created using ArcGIS 10.1 software. These parameters were analyzed to prepare landslide susceptibility zones, which is depicting the probability of occurrence of landslides. This study deduces that present scenario will lead to the future; weightages of each parameter were calculated on the basis of landslide inventory (2014), as a Frequency Ratio (FR). Higher is the landslide frequency, higher will be weightages. The sum of weightage of FR of the variables was used as landslide susceptibility index (LSI). Five landslide susceptibility zones were classified based on the LSI and were validated using 50 active random landslide locations and grid pixels. The AUC value was calculated 0.812 shows that the 81.2% of landslides have occurred in the high and very high landslide susceptible zones. Thus FR method is very significant for the probabilistic analysis of landslides along the highway corridors in the Himalayas for policy implications.

1. Introduction

Landslides are the products of changes in the environmental parameters. Every year, a large number of landslides occur in the Himalayas; due to younger geological formations and tectonic movements. The situation turns out to be worse during the South-west (SW) monsoon season. In addition to the geo-environmental setting, increased human activity in the area aggravates the landsliding phenomena to turn into a disaster.

Landslides are triggered by two principle forces; earthquakes (Shroder and Bishop, 1998; Paul et al., 2000; Umar et al., 2014; Shafique et al., 2016; Singh and Som, 2016) and concentrated spells of rainfall (Paul et al., 2000; Barnard et al., 2004; Wang and Sassa, 2006; Durga Rao et al., 2014; Huang et al., 2015; Allen et al., 2015). Recently constructed highways have greatly influenced the economy and transport and communications, catering to the remote villages of the Himalaya. These regions are tectonically active, and are characterized by younger geological formations, fragile topography and adverse climatic conditions. All these factors have a crucial role to play in triggering landslides; and further, reactivation of landslides which have happened in the past, in the Himalayas (Burbank et al., 2012; Gallo and Lavé, 2014; Allen et al., 2015). Therefore, it is necessary to prepare a landslide susceptibility map to predict landslide locations on regional and local scales in the light of active tectonics and extreme rainfall events, while addressing the issues of developmental plans and infrastructure upgrade. To analyse the landslide susceptibility, a variety of methodologies have been developed worldwide. Geographic Information System (GIS) and associated tools have improved mapping techniques; along with statistical and semi-statistical modeling to numerous approaches; such as fuzzy systems, neural networks, spatial multi-criteria evaluation, index of entropy, neuro-fuzzy models, random forest, multivariate weights of evidence, information value method, multiple linear regression analysis, discriminant analysis, logistic regression analysis and frequency ratio (Carrara et al., 1999; Wang et al., 2005; Lee, 2007;

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Lee and Pradhan, 2007; Yilmaz, 2009a, 2009b; Pourghasemi et al., 2012; Reza et al., 2012; Pourghasemi et al., 2013; Dou et al., 2015; Youssef et al., 2015; Pham et al., 2016; Mohamed et al., 2016; Pourghasemi and Rossi, 2016; Reza and Norman, 2016; Hong et al., 2016a, 2016b; Chen et al., 2017a, 2017b). Frequency ratio, weight-of-evidence and analytical hierarchy processes (AHP) are the quantitative statistical approaches for the study of landslides. These methods often use a landslide inventory as a predictive variable in the modeling processes, with respect to independent variables. The axioms of frequency ratio are that landslides have occurred in the past; future landslide will occur in the similar geo-environmental setting (Lee and Talib, 2005; Lee and Sambath, 2006; ilmaz, 2009; Yalcin et al., 2011; Pourghasemi et al., 2012; Youssef et al., 2015; Hong et al., 2016a, 2016b). There has always been a question about the sensitivity of statistical methods in calculating the weightages of independent variables. The use of landslide inventory has reduced the problem of sensitivity, partially with the application of statistical models that are more robust, and mathematical tools with more rigorous validation processes (Beguería, 2006; Ghosh et al., 2011; Guzzetti et al., 2012; Poiraud, 2014).

During the last two decades, increased development activities along with extreme climatic events has turned out to be quite disastrous in the region (Allen et al., 2015). Significant land use and land cover changes have been observed in the study area post Tehri Dam construction (Kumar and Anbalagan, 2015; Pandey, 2015). Unscientific land use, alongside prolonged spells of rainfall during the south-west monsoon season, could lead to higher landslide susceptibility of the region (Paul et al., 2000; Srivastava et al., 2013; Pandey, 2015). The objective of the study is to analyse the areal distribution of landslide and preparation of landslide susceptibility zones along the Tipari-Ghansali-Ghuttu road corridor. This route section is one of the major stretches of Uttarakhand, frequently used by pilgrims during rainy season.

2. Study area

The study area is located along the Bhilangana river in Tehri Garhwal district of Uttarakhand within 78°29′57.82″ E to 78°48′14.15″ E longitude and 30° 21′31.36″ N to 30° 32′32.47″ N latitude covering an area of about 183.97 km^2 (Fig. 1). The area is highly vulnerable to landslides during the monsoon season. To analyse the landslide susceptibility, a 5 km buffer has been taken along the highway which is aligned with the length of the Bhilanagana River.

Physiographically, the area is situated in both the Lesser and Great Himalayan ranges. The altitude of the study area is ranges between 733 and 2643 m making it a high relief terrain. The rock formations are broadly grouped under two categories: the Lesser Himalayan meta-sedimentary and the Higher Himalayan crystalline (HHC), respectively. The Lesser Himalayan rock groups belong to Chandpur, Nagthat formation of Jaunsar Group and Blaini formation of Mussoorie Group; Deoban and Mandhali formation of Tejam Group, and Berinag formation of Jaunsar Group respectively (Valdiya, 1980). The Higher Himalayan crystalline (HHC) rock formations include granite and gneiss of Vakirta and Munisiari groups to the north of the Main Central Thrust (MCT). Chandpur rock formation covers the area between Tipari and Pipaldali, with low grade metamorphosed lustrous phyllite and highly weathered quartzite (Rao and Pati, 1982). It is separated by the North Alomra Thrust (NAT) from the Jaunasar group. Deoban group rocks consist of fine grained dolomitic limestone with minor phyletic intercalations. These rocks are mainly confined along the higher ridges. Berinag formation is separated by the Berinag thrust at its base, consisting mostly of quartzites rocks. Main rock types are schist, phyllite, gneiss, quartzite and dolomite respectively.

Sub-tropical to temperate climatic type is found in the area which strictly follows altitudinal variation as well as vegetation zones. Approximately, 85% of the annual rainfall occurs during the SW monsoon season in the area, which induces a large number of landslides. The average annual rainfall is 1210 mm that occurs in concentrated spells of 68 rainy days annually.

3. Materials and methods

In the present study, Survey of India (SOI) topographic maps on RF 1:50,000 series (1962-63) have been used to vectorize contour map on 20 m interval for generation of digital elevation model (DEM) using ArcGIS 10.1 software. This DEM was further used to prepare gradient, aspect, slope curvature and drainage extraction. Landsat-7 ETM+ Path 146 Row 039 dated 2nd November 2009; ID: LE71460392009306SGS00 satellite image was used to prepare a landslide inventory. Land use/ land cover of the study area has been updated using IRS-2 LISS 4 FX Sub-scene C Path 097 Row 049, dated 18-

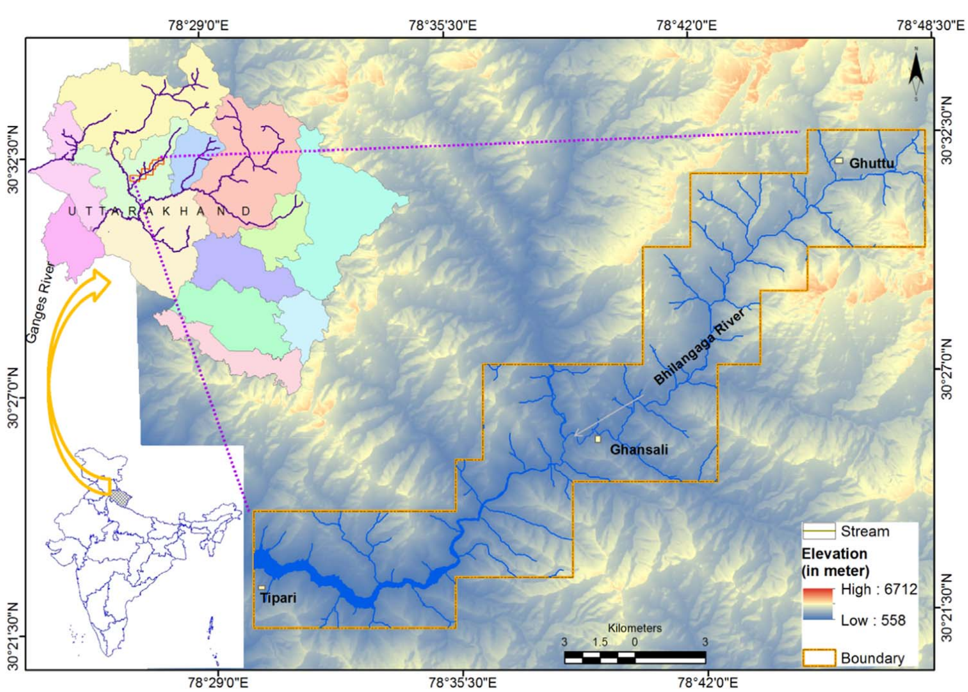

Fig. 1. Location map of the Study area, District Tehri Garhwal (Garhwal Himalaya, Uttarakhand).