Rainfall-Induced Landslide Hazard Assessment along NH 1D from Ganiwan to Gumri (J & K), India

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Abstract

The aim of this study is to generate reliable susceptibility maps using weights of rainfall events and landslide occurrence models based on (land-area-based/location) using geographic information system (GIS) and remote sensing for the NH 1D from Ganiwan to Gumri, Jammu, and Kashmir. At first, landslide locations were identified by earlier available reports, aerial photographs, and field surveys and a total of 221 landslides were mapped from Ganiwan to Gumri along NH 1D since 1992-2011 from different sources. The present study reveals that 114 landslide events were found to have a significant correlation with rainfall occurrence and remaining landslide episodes seem to have occurred due to lithology and slope factor. The landslides were categorized into five categories on the basis of the frequency of occurrence over a period of time from 1992 to 2011. The results of the statistical analysis with the general linear regression model showed that the maximum landslide occurrence is explained by rainfall increase except at ascertain point of time where landslide occurrence seems to be related to other factors as well.

Keywords: Landslide, Rainfall, Causative Factors, J&K, NH 1D

INTRODUCTION

Landslides, a recurrent problem throughout the world, have caused extreme damage to life and property worth billions of dollars (Kumar *et al.*, 2017). Landslides triggered by heavy rainfall have been discussed thoroughly by different workers (Sah, 2007; Sati *et al.*, 2011; Rana *et al.*, 2011; Kumar *et al.*, 2017) to (prove) the complex land and rock-based processes that threaten the basic social fabric including people, (basic equipment needed for a business or society to operate), communication networks and farm-related land (Saro *et al.*, 2002; Ali and Fikri, 2007). External or internal factors, including steep slope, removal of support from the slope, adding water/moisture in different forms, fundamentally weak material, may trigger landslides. Determination of landslide susceptibility mapping and occurrence is a complex physical process in risk-related management to secure/make sure of the safety of human life and to avoid negative effects on (related to a large area) and national economy (Chauhan *et al.*, 2010). Therefore, landslide (method) understanding is significant in land risk management in mountainous areas. Worldwide, Nepal and also in Indian Himalayan area, large number of studies have been carried out to identify the causative factors for landslides, by creating landslide susceptibility maps (Gabet *et al.*, 2004; Kanungo *et al.*, 2006; Guzzetti *et al.*, 2007; Alvioli *et al.*, 2014). Production of accurate and detailed landslide susceptibility maps have been

well studied topic in risk-related management. These maps provide valuable information for the government (services businesses/government units) and decision makers to make emergency plans to lessen negative effects on human life, infrastructure and farming-based land (Kavzoglu *et al.*, 2014). Landslide hazard evaluation and mapping based on rainfall strength-length of time threshold in affected areas are attained through accurate information on landslide events and connected rainfall conditions (strength and amount). Therefore, landslide susceptibility mapping is a significant step prior to landslide assessment planning, management, and disaster mitigation. Identification and detailed assessment of this undervalued hazard is needed in effective landslide hazard reduction through disaster mitigation planning and development strategies (Calligaris *et al.*, 2013; Ahmed *et al.*, 2014). A large number of studies have been carried worldwide and also in the Indian Himalayan area, which helped in identifying the causative factors for landslides. (Gupta, 1999; Arora, 2004; Saha, 2005; Chauhan, 2010 and Kanungo, 2006). In the Indian Himalayan area landslide driven dangers/risks have intensified over the past 20 years mostly caused by the event of heavy and extreme rainfall. In the mountainous regions of Jammu and Kashmir, 70% of rainfall (rain, snow, etc.) during the winter-spring maxima is produced by the western disturbances and convectional activity. While during the late summer the intense (rain, snow) is caused by maritime incursions from the Indian Ocean provided that they are strong enough to cross Pir Panjals (Dimri and Dash, 2012). Keeping in view the above-mentioned limitations, a described/explained landslide survey was carried out in the selected sites. The most important goal of the present study was to understand the causative factors for the development of landslides by integrating meteorological conditions using (related to the weather) data, pre-post- disaster scenario using satellite imagery in line with topographic maps and characteristics of the local terrain. The present study identified the meteorological factors contributing to landslide event along the NH 1D from Ganiwan to Gumri stretch.

MATERIAL AND METHODS

Study Area

The study area from Ganiwan to Gumri along NH-1D lies in the western section of Great Himalaya with an average altitude of 3000 to 4000 meter a.m.s.l. with spectacular Zojilla Pass (3528m). Geographically, it is situated between 34° 18'11" N to 34° 32'28" N and 75° 17'35" to 76° 08'21"E. The total length of the study area along NH ID highway from Ganiwan to Gumri is 54 Km (Fig.1). The climate is characteristic of the Mediterranean type with temperate in summers and rainy season normally lasting from late winter to early spring with occasional rainfall during early autumn provided monsoon currents are strong enough to cross the Pir Panjal region.

Lithology

Lithology is one of the primary factors in landslide occurrence because different lithological units lead to differential strength and permeability of rocks and soils. Numerous researchers such as Dai *et al.*, 2001; Yesilnacar and Topal, 2005; Yalcin and Bulut, 2007; Nefeslioglu *et al.*, 2008, have used lithology for landslide susceptibility analysis. The types of regolith material have a strong relationship with slope instability (Derbyshire *et al.*, 2000; Avanziet *et al.*, 2004; Wakatsuki *et al.*, 2005; Sidle and Ochiai 2006). Weathering modifies the mechanical, mineralogical and hydrologic characteristics of regolith (Chigira 2002; Wakatsuki *et al.*, 2005). The quartzite, shale, phyllite, schist, sandstone, and limestone, interposed by Quaternary gravel and silt, are the predominant rock types observed in the study area. The lithological map of the study area is adopted from Thakur and Rawat (1992). The geological formations are grouped into six classes: (i) Amygdaloidal Basalt (Permo-carboniferous), (ii) Bedded Limestone, (iii) Sandstone/Claystone/Siltstone, (iv)

Massive Granite, (v) Shale/Schists/Phyllites, Quartzite Beds, (vi) Gravel, Sand, Silt with Clay (Quaternary).

Fig 1: Location map of study area showing the catchment of landslide area along a road stretch of NH-1D (Source: SOI toposheets, 1971 and ASTER DEM).

Table-1: Distribution of lithological units

S. No.	Rock units	Area in sq. km	Percentage
i	Gravel, Sand, Silt with clay	35.72	5.04
ii	Shale/ Schist/Phyllite Quartzite	364.30	51.38
iii	Sandstone/Claystone/Siltstone	192.80	27.19
iv	Bedded Limestone and Sandstone	55.22	7.79
v	Amygdaloidal Basalt	50.42	7.11
vi	Massive Granite	10.54	1.49
Total		709	100

Source: Computed from Landsat ETM 7 satellite data, September 2016 and ASTER DEM.

The major part of the study area consists of Shale/Schist/Phyllite with Quartzite with 364.30 sq.km (51.38%) followed by Sandstone/Claystone/Siltstone 192.80 sq.km (27.19%) as shown in (Table-1 and Fig. 2).

Data collection

The study of the correlation of rainfall and landslides requires the collection of many variables in spatial and temporal distribution. For this reason, firstly, a database of

landslide phenomena was constructed for the period 1992-2011 and in the process, all the factors causing these phenomena were analyzed. This dataset was collected from various published and unpublished sources, governmental and field agencies with a significant quantum of landslide data from Border Roads Organization (BRO), Srinagar and Haripora. As the study area lies in the data scarce region where not a single meteorological station is established, so the data provided some hiccups during the course of study. The rainfall data were obtained from Indian Meteorological Department, Srinagar and globalweather.com which provides some good daily data. In order to examine the relationship between rainfall and landslides, a database concerning daily maximum, monthly and annual rainfall totals were constructed. This was correlated with the number of landslides at different scales like monthly and annual basis.

Fig. 2: Lithology map of study area (Source: Thakur and Rawat, 1992; landsat ETM 7 satellite data, 2016 and ASTER DEM)

Statistical analysis

Linear regression analysis was performed to know the nature (+ve or -ve) and magnitude of the relationship among landslide occurrence and rainfall. First, we found the best fit model (largest r^2) for exploring whether there was a significant relationship among landslide occurrence and rainfall.

RESULT AND DISCUSSION

Rainfall/Precipitation Analysis

The correlation of the rainfall and landslide events was initiated mainly by (Gaine 1980) and continued later by other researchers (Keffer *et al.*, 1987; Grozier, 1999; Wilson and Wiczorek 1995; Guzzetti *et al.*, 2004; Aleotti, 2004; Glade *et al.*, 2005). The aforementioned authors studied either empirical relationships between rainfall and landslides by constructing intensity duration curves, or physical processing models.

A total of 221 landslide events have been recorded from Ganiwan to Gumri along NH 1D since 1992-2011. Since present investigation assessed the correlation between landslide occurrence and rainfall from 1992-2011. In the present study, 114 landslide events were found to have a significant correlation with rainfall occurrence and remaining landslide episodes seem to have occurred due to slope factor. The analysis of the data from 1992 to 2011 revealed that the study area has received highly erratic and uneven distribution of rainfall. The monthly and annual analysis reveal that February proved to be highly precipitous month followed by March which is directly correlated to the weather patterns over the study area at these time periods which owe their significance to the western disturbances and local convectional activity. Late winter and early spring seasons have received huge rainfall. The inter annual data reveals that in the initial years (1992-96) of the study period, huge rainfall events have been witnessed which decreases towards the end of the period with some extreme events. Monthly Rainfall analysis reveals the dominance of winter and early spring rainfall with February being the most precipitous month followed by March and then April. Rainfall goes on decreasing as we move towards summer and autumn season which then goes on increasing towards winter season are shown in Fig. 3.

Fig. 3: Average monthly rainfall from 1992 to 2011 (Source: Indian Meteorological Department, Srinagar)

The annual analysis of the rainfall reveals that average annual rainfall during the study period hovered around 592.5 mm. During 1992, the study area received the highest

rainfall of 1074.5 mm followed by 1994 with 1008.2 mm rainfall. The lowest rainfall of 223.1 mm was received during 2001 followed by 2000 with 380.7 mm as shown in the Fig. 4.

Fig. 4: Total annual rainfall from 1992 to 2011 (Source: Indian Meterological Department, Srinagar).

Landslide Events

The analysis of the annual rainfall and annual landslide data over the 54 km stretch from Ganiwan to Gumri revealed a positive correlation of 0.34 between a number of landslides and amount of rainfall. This shows the dependence of landslides on the amount of rainfall. The landslide events multiplied in numbers as the amount of rainfall showed positive deviation from the average value of 592.5 mm while it showed a negative trend when the rainfall recorded was below average. The landslide occurrence was also found to be influenced by the lithologies and slopes (Fig. 2 & 7). The number of landslide events monthly and annually during the study period is depicted in Fig. 5 and Fig. 6. The number of landslides varied from 6 to 40 for different months. The highest number of landslides was recorded in the month of September with 40 landslide events while the lowest number of landslides was recorded in the month of December (6 events) shown in Fig. 5.

There are uneven numbers of landslides in different years, which do not show any definite pattern. The number of landslides varied from 1 to 48 from different years. The highest number of landslides was recorded during 2006 with 48 landslide events recorded at 7 sites from Ganiwan to Gumri road stretch of NH-1D followed by 1995 with 32 events of landslides whereas the lowest number of landslides was recorded during 2007 (1 event) as shown in Fig. 6.

Fig. 5: Monthly variation in the number of landslides from 1992-2011 (Source: BRO, Rengreth and Srinagar)

Fig. 6: Number of annual landslides from 1992 to 2011 (Source: BRO, Rengreth and Srinagar).

Fig. 7: Slope map of the study area (Source: SOI toposheets, 1971 and ASTER DEM)

Fig. 8: Annual average rainfall (mm) with respect to landslides dates, for different sites of NH 1D (Source: BRO, Rengreth and Srinagar and Indian Meteorological Department, Srinagar).

Fig. 9: Percentage (%) of annual rainfall and the respective annual percentage (%) of landslides, for different sites of NH 1D from Ganiwan to Gumri. (Source: BRO, and Indian Meteorological Department, Srinagar)

Fig. 10: Monthly rainfall totals as a percentage (%) of the respective annual rainfall totals with respect to landslides dates, for different sites of NH 1D from Ganiwan to Gumri. (Source: BRO, and Indian Meteorological Department, Srinagar)

The statistics of the annual, monthly and maximum daily rainfall totals associated with the recorded landslides in the wider area of Ganiwan to Gumri are shown in Fig. 10. It is clear that in most of the cases, extreme rainfall events are associated with landslide developments. In order to examine the rainfall impact on the development of landslides, the annual rainfall recorded in the specific years when landslides happened in the study area is depicted in Fig. 9. Another significant parameter which is closely related to the onset of landslides is the maximum daily rainfall totals. Extreme daily rainfall events, that in many cases exceed 76.5 mm, which is a threshold of heavy rainfall events (Nastos and Zerefos, 2008), seem to be typical for the development of landslides in areas that are also vulnerable to other physical factors. Another significant parameter which shows the dependence of landslides with rainfall events is their correlation, and the results showed that there exists a positive correlation of 0.34 between these two events. On the basis of the information obtained from the present investigation, the study area was classified into five categories on the basis of the frequency of occurrence over a period of time from 1992 to 2011. (Fig. 11).

Fig. 11: Spatial distribution of landslides with the frequency of occurrence (Source: Generated from, Thakur and Rawat, 1992; landsat ETM 7 satellite data, 2016 and ASTER DEM)

The perusal of the results reveals that the rainfall regime and the maximum occurrence of landslides at certain specific sites is explained by the lithological reasons. Quaternary deposits (Gravel, Sand, and Silt with Clay) and Premocarboniferous rocks, (Shale/Schists/Phyllites Quartzite Beds) tend to absorb the moisture content from the hydrological regime, either through rainfall/snowfall which is a common phenomenon observed in the study area. Moreover, the rainfall/snowfall in tends to decrease the shear strength of the lithologies present in the study area. In addition to that, the slope angle range between 30-50° is a feasible angle for slope to fail. The above phenomenon leads to frequent occurrences of landslides on the three sites of the Ganiwan to Gumri stretch.

Regression analysis (Fig. 12) was performed to estimate or predict the magnitude of the relationship between the variables like rainfall and landslide. The r^2 value (coefficient of determination) represents the proportion of variance in the dependent variable that can be explained by our independent variable (technically, it is the proportion of variation accounted for by the regression model above and beyond the mean model). The results of the statistical analysis with the general linear regression model showed that the maximum landslide occurrence is explained by rainfall increase except at the certain point of time where landslide occurrence seems to be related to other factors as well.

CONCLUSION

Since landslides present a huge risk to the human life and property, studies about their origin, movement, identification, and management become very extremely important for (making something as small as possible/treating something important as unimportant) the losses. An identification and management of landslides will be possible only after the identification of causative factors which are responsible for landslide event. Rainfall has always been a first (or most important) cause in triggering landslides that too at high/higher places with high slope and unstable topography like one in the Himalayas. In the present study, a relationship has been shown between the landslides and rainfall along a 54 km road stretch which is strategically very important and always faces the problems of landslides. The present study analyses that most of the landslides during the study period are basically triggered due to heavy rainfall events. This is further explained by the fact that the frequency of landslide occurrence is also governed by the nature of lithology. The maximum occurrence has been recorded on those sites where the lithology favours the initiation of landslides.

Fig. 12: Showing nature of the relationship among landslide and rainfall with a linear regression model.

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