A multi-temporal landslide inventory and hazard zonation using relative effect method along the Mughal road Shopian, India

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Abstract
Landslide inventory and thematic data are of utmost importance in the domain of landslide hazard mapping. The union territory of Jammu and Kashmir, India surrounded by the Himalayan and the Pir-Panjal mountain range is prone to landslides and has already caused havoc at many places. The present study aims to provide the landslide inventory of the Mughal Road, Shopian, which lies in the Pir Panjal range of Kashmir valley. Multidate satellite data of the years 2008 to 2020 are utilized to create an inventory of landslides in this area.The use of high-resolution satellite imagery made it possible to delineate the shallow as well as the deep landslides along the roadside where they occur frequently. To understand the landslide causes, a statistical technique, relative effect method has been implemented in this study. This method helped in mapping the hazard zone areas. The relative effect of each causative factor on landslides is determined by calculating the ratio of coverage and slide which were analyzed in GIS environment.

The resulting landslide hazard zone map has been classified as very low, low, moderate, high and very high zones. Out of the total area, 12.62% is critical to landslides, 21.45% is highly prone and 24.84% is moderately prone while 21.94% is low and 19.13% is very low prone to landslides. The outcome of this susceptibility modeling will be beneficial for handling and monitoring the forthcoming landslides as well as the fortification of the general public and environmental hazards of the study area. It will also help the planners in the development around the study area.

Keywords: Mughal road, landslides, GIS, satellite data, relative effect method.

Introduction

Slope instability, either soil or rock failure where material constantly keeps moving downwards is termed as landslide.[11,12,33] They are considered hazardous when they hit an area which is desolate; however, when it covers a populated location, it is considered as disaster.[9] Among the various natural hazards of mountainous region, landslide is reflected as one of the threatened disasters worldwide. Most of the times, it is associated with other hazards like seismic activity, inundations or storm. Due to its alignment with other hazards, individual landslides are not considered as much spectacular like other disasters in the sense of cataclysm.

To map such landslides, the present day earth observation satellites carry a variety of image sensors to observe the changes in the earth features and the causative factors for landslides and how the space data are helpful to predict and prevent the landslides.[25] To recognize small scale and shallow landslides, remote sensing data that provides at least 10m spatial resolution is required. Landsat TM data can be used[20,21] but higher resolution SPOT PAN(10m), IKONOS (4m) or InSAR (Singhroy2000) data are preferred for this application.

Landslides were detected using Landsat ETM+ imageries in the Himalayas.[28] SPOT and IKONOS satellite imagery have been used for the documentation of shallow landslips on Lantau Island, Hong Kong.[26] It is important to have a good understanding of the different conditions which results in slope instability and processes that activate them and their place of occurrence where they are likely to occur and what possible destruction they may prevail.[13]

In literature, mostly the classification scheme is based on the movement, velocity and type of material which trigger landslides. Falls, topples, lateral spreads, slides, flows and complex are classified on the basis of movement and each class was sub classified with respect to material nature like bedrock, debris (predominantly coarse soil) and earth (predominantly fine soil) except complex landslides which occur due to the integration of two or more than two types of movements.

Landslides can be active, inactive as well as dormant and relict.[38] They can be also categorized on the direction and type of movement and the presence of carrying mediator like water, ice or air.[10] Terrain instability, slope failures and slope instability are main causes of landslides.[22] Landslides can be classified on the basis of two types of factors: intrinsic and extrinsic. Intrinsic factors include geology, geomorphology and hydrology whereas rainfall, earthquake, volcanic activity and human activities are included in extrinsic factors.[42]

Landslide inventory maps can be prepared into several ways such as reconnaissance inventory maps, geomorphological inventory and multi temporal map.[14] Multi temporal landslide inventory is used to determine the spatial, temporal and landslide size probability.[18] Landslide inventories can never be complete because landslides are of different kinds depending upon innumerable combinations with respect to their activating and environmental factors. Landslide mapping using a very high resolution satellite images has become a finest selection. Satellites like IKONOS, CARTOSAT and Quickbird have been used widely for creating a geodatabase of such kind of events.[7,19] Landslides can be mapped in various ways using satellite imagery[34], geomorphologic field mapping[5] and aerial photography.[35] With the use of various thematic parameters in GIS, it is possible to prepare landslide hazard and susceptibility maps. With the integration of GIS and IRS-1C LISS data, seismic ground hazard maps were created for Sikkim Himalaya.[23]

The technique of preparing landslide inventory map explicitly depends on the extent of study area, scale, research purposes and available resources. In the Himalayas, landslides rank third in terms of number of losses due to natural calamities and the projected average fatalities due to landslides account for 200 lives and Rs 500 crore every year.[24] The occurrence of these landslide induced losses is peculiarly on the rise along the novel motorway divisions within the complex Lesser Himalayan environment.[17,31,36]

In this study, we attempted to create an inventory of landslides along the Mughal road through Lesser Himalayan Orogenic belts of the North West Himalaya. An attempt was made to create a Landslide Hazard Zonation map which will help in identifying the various hazard zones according to degree of actual potential hazard from landslides on slopes.[39] Many researchers have used different techniques to generate the LHZ maps.

Ghafoori et al[15] generated landslide hazard zonation using relative effect function in Bormahan basin, Iran. RE method can be used to determine the relationship between the landslides and the factors responsible for triggering them.[30] Bera et al[4] differentiated the area into various hazard zones with the help of relative effect method in Raigad district of Maharashtra.

The relative effect method is a statistical based model which predicts area of possible forthcoming landslides on the basis of association between past landslide incidence and its causative factors. Each causative factor is enclosed independently by the landslide. For every causative factor, the proportion of the class area to the total area of the study and the proportion of the landslide area in the class to the total landslide area are calculated. The study area i.e. Mughal road is approximately 83.9 km long, out of which 45 km is highly zigzag as shown in figure 1.

Study area

Mughal road which connects Kashmir with the rest of the country, India, is considered as an only alternate route after National Highway NH44. The road is 83.9 km long and passes over Pir Panjal Mountain range with an altitude of 3474.72m (11,500ft). It is higher than the Banihal pass (2,832 m) of NH44. Out of 83.9 km, almost 45 km long road is highly zigzag with hair pin bends. The road passes through Shopain, Hirpora, Dubjan, Zaznar, Aliabad, Peerkigali, Chattapani, Poshana, Chandimarh, Behramgalla and Buffliaz. The average elevation ranges from 1500 m to 4600 m. Two rivers Suran and Rambiara pass through this area. It receives an average annual rainfall of about 1011.55 mm.

The peak precipitation time is during the months from May to August and it starts declining in the month of September after which snowfall is dominated over the region. The area experiences heavy snowfall from November onwards until the early April. Also the area is seismically active and falls under seismic zone IV and V.

Data sets and methodology: Remote sensing and GIS are integrated to carry out the study in this region. Current land sliding along the Mughal road with a length of 51.57 kms was mapped using two high resolution Multidate satellite images World View of 2020 and CARTOSAT 2 of 2008 with spatial resolution of 0.6 and 1m respectively on a scale of 1:2000. ArcMap 10.2 which is the central application in ArcGIS has been used for database creation and GIS based analysis (Table 1). The Google Earth as well as the field survey were carried out for validation of the results.

The causative factor layers such as lithology, geology, geomorphology, slope, aspect, elevation, NDVI, drainage density, lineament density, land use land cover, road density and rainfall (Figure 2) were prepared in GIS. RE factor of each class on landslide was obtained through an algorithm and each factor was summed up in order to generate the hazard zonation map of the study area.

The relative function can be calculated as:

$$\mathrm{RE} = \mathrm{Log}\left[\frac{\%\,of\ coverage}{\%\,of\ slide} + \varepsilon\right] \tag{1}$$

where ε is a very small positive value near zero.

If RE value of individual causative factors is less than zero, it has no effect on landslide incidences. If it is greater than zero, it means it has a greater effect on landslide incidents and if zero, then it has no effect on increasing or decreasing landslide risk.

After calculation of RE of all the causative factors, LSI was calculated using the equation:

$$(\mathrm{LSI}) = \sum REs \times \alpha$$

where RE is the rating of each factor's type or range and LSI = Landslide Susceptibility Index.

Figure 2 displays the Lineament density map, Drainage density map, Slope, Elevation and Aspect map which have been generated using ALOS PALSAR DEM. Rainfall map was generated through IMD data. NDVI and LULC were generated from LANDSAT OLI (2020) whereas lithology, geology and geomorphology have been generated from the field survey and vector data was provided by GSI. All the thematic layers were generated in ArcGIS 10.2 software.

Table 1
Datasets used for the study area

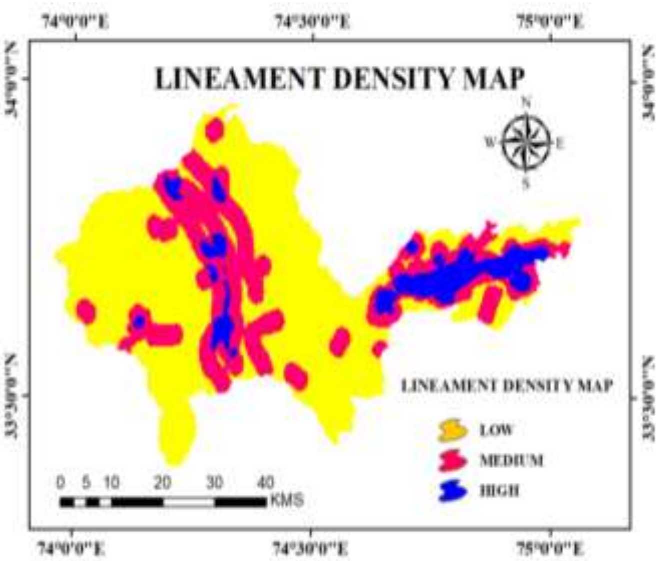
Dataset	Year	Month	Resolution
CARTOSAT 2	2008	April-October	1m(PAN)
World View	2020	September	0.6 m

Results and Discussion

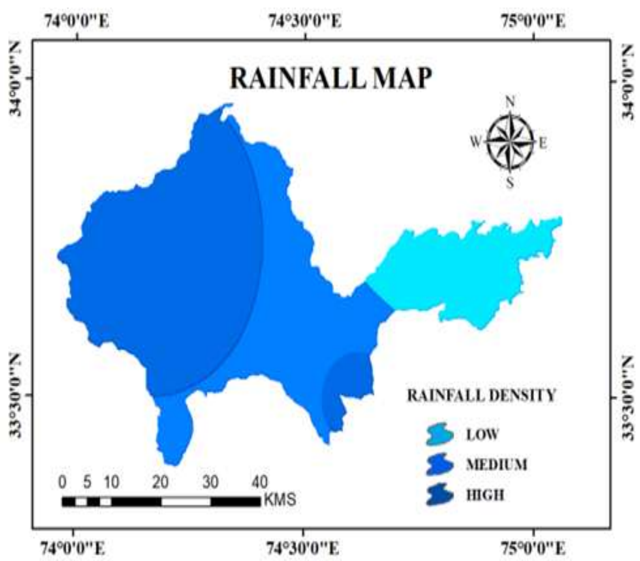
In the year 2008, a total number of 122 landslides were interpreted through digitization (figure 3) while as in 2020, 185 number of landslide scars were delineated (figure 4). Out of the 185 landslide scars, 145 are inactive which constitute about 78 % while 40 are active i.e. 22 %. We found very less or no vegetation cover at the active landslides and it is supposed to be the main reason for frequent landslides in this region. Deforestation along the roads has also added to the slope instability. The road comprises of both shallow as well as deep landslides. Apart from being active, they are convex in nature as well.

According to a report from District Disaster Management Shopian and Regional Transport Office Shopian, in the year of 2005 (8th of October), a landslide hit at the Mughal road in which at least a dozen of the sheep were killed and almost 8 km of road was washed away.

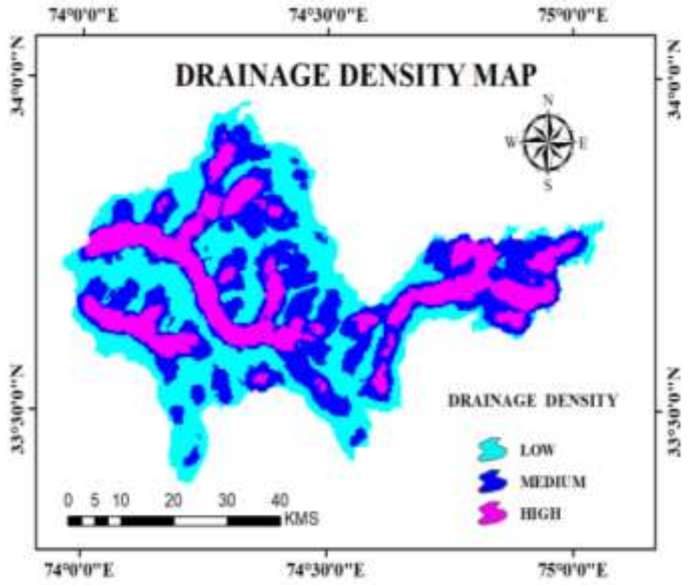
Figure 1: Hair pin bends along the Mughal Road



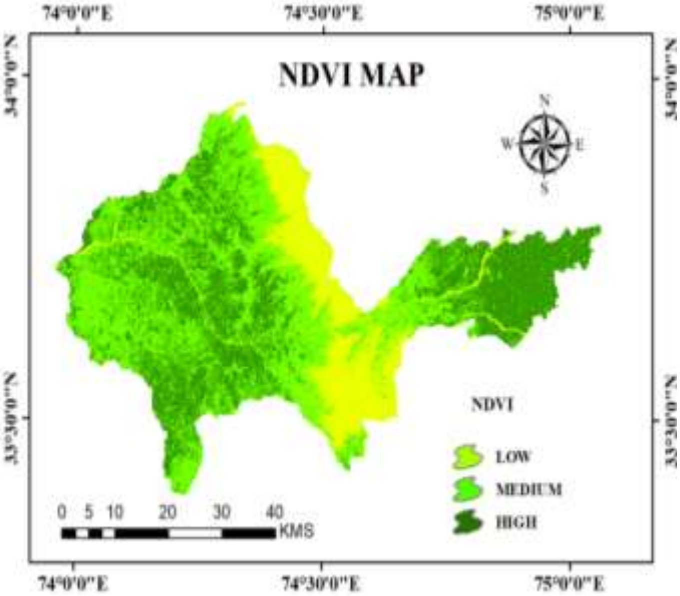
(a)



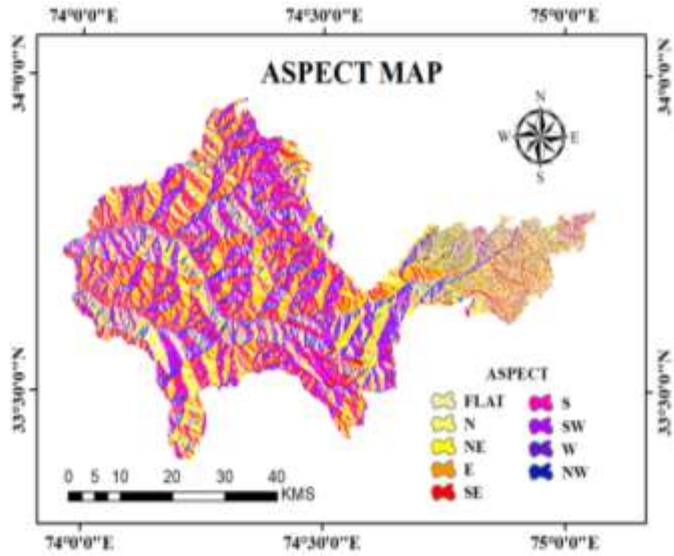
(b)


DRAINAGE DENSITY MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
S
E
W
DRAINAGE DENSITY
LOW
MEDIUM
HIGH
0 5 10 20 30 40
KMS

(c)


NDVI MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
S
E
W
NDVI
LOW
MEDIUM
HIGH
0 5 10 20 30 40
KMS

(d)


ASPECT MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
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W
ASPECT
FLAT
N
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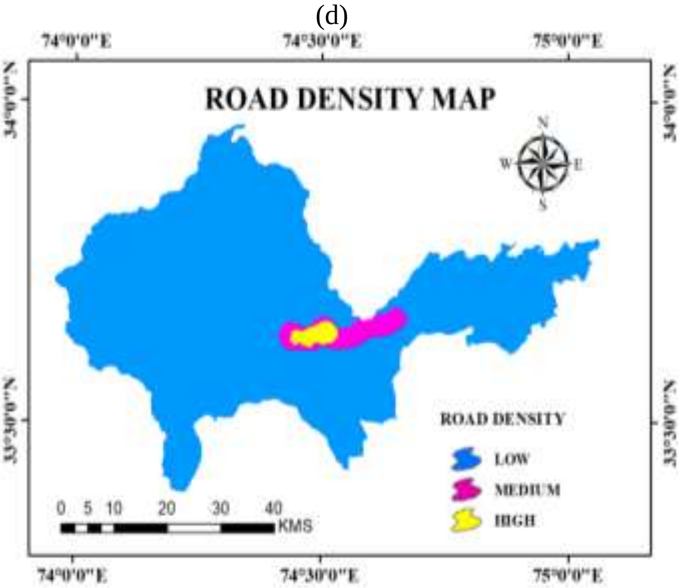
E
SE
S
SW
W
NW
0 5 10 20 30 40
KMS

(e)


ROAD DENSITY MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
S
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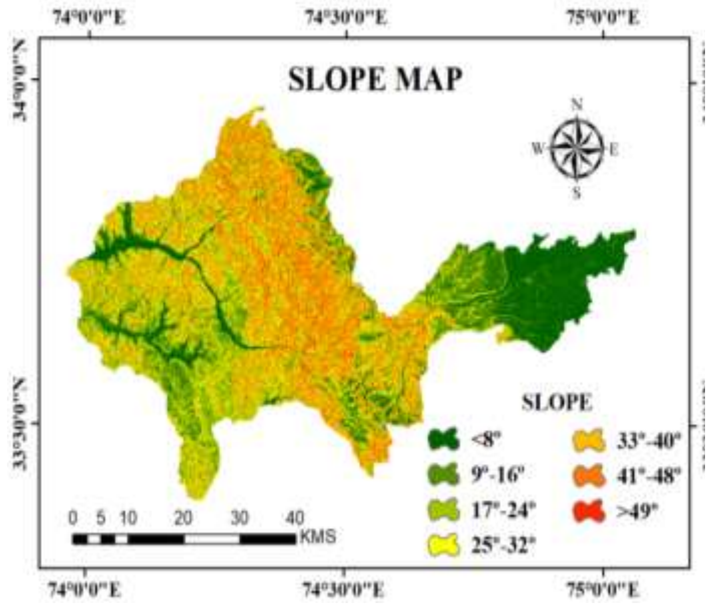
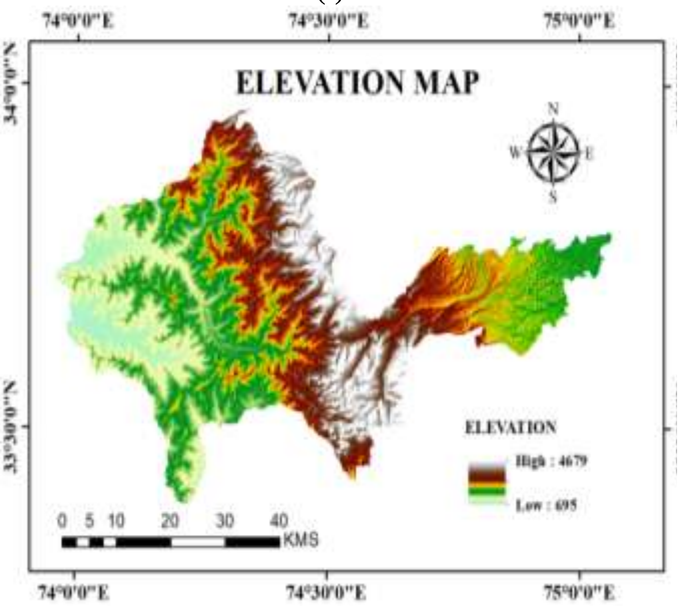
ROAD DENSITY
LOW
MEDIUM
HIGH
0 5 10 20 30 40
KMS

(f)


SLOPE MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
S
E
W
SLOPE
<8°
9°-16°
17°-24°
25°-32°
33°-40°
41°-48°
>49°
0 5 10 20 30 40
KMS

(g)


ELEVATION MAP
74°0'0"E
74°30'0"E
75°0'0"E
34°0'0"N
33°30'0"N
N
S
E
W
ELEVATION
High : 4679
Low : 695
0 5 10 20 30 40
KMS

(h)

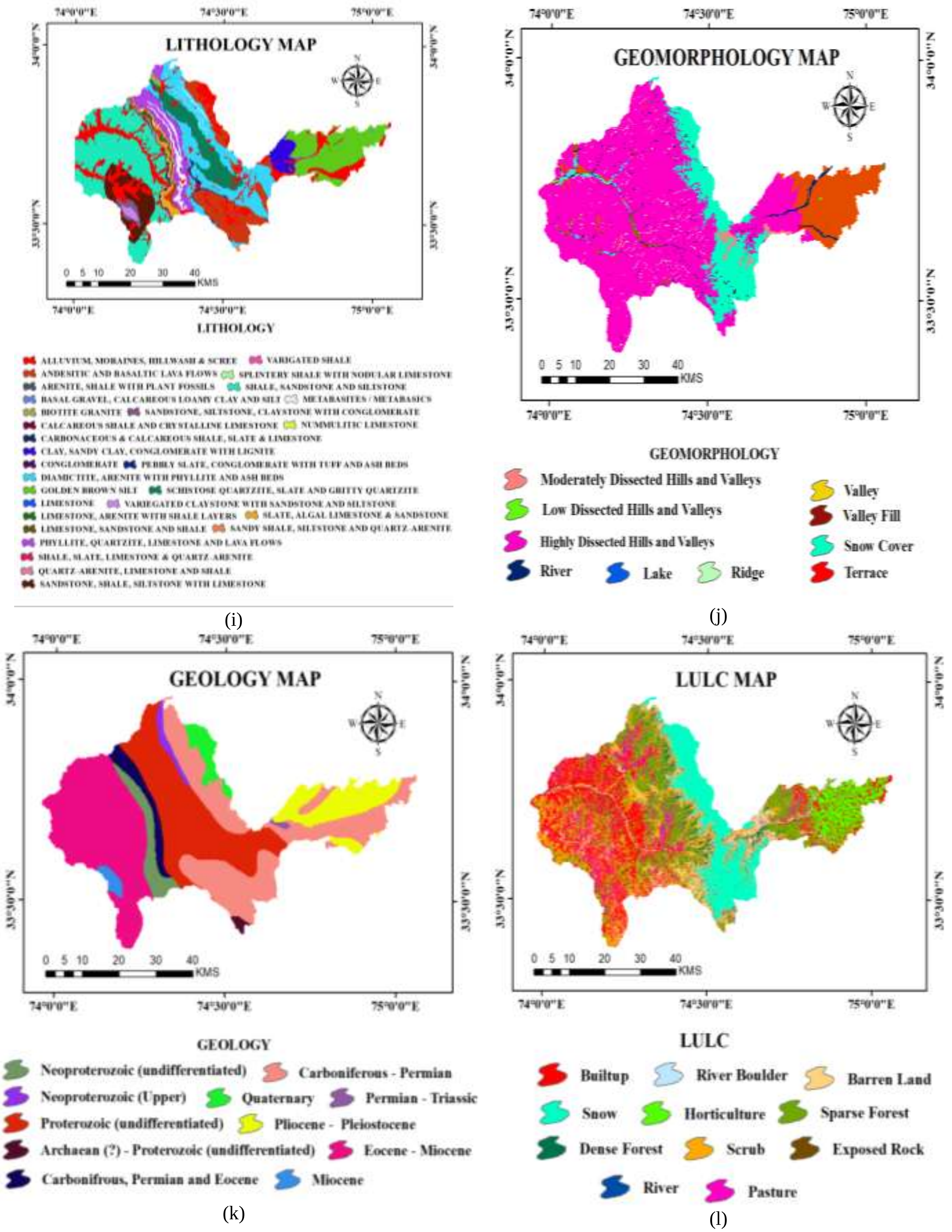


Figure 2: The different thematic layers used as causative factors for Landslide (a: Lineament density, b: Rainfall density,c: drainage density, d: NDVI, e: Road density, f:Aspect, g: Slope, h: Elevation,i: Lithology, j: Geomorphology, k: Geology, l: LULC)

Here, in our study location, the area is classified into five zones which are very low, low, moderate, high and very high (Fig. 5). In table 2, all the hazard classes have been computed according to their pixel numbers and area percentage. Out of the total area, 12.62% is critical to landslides, 21.45% is highly prone, 24.84 is moderately prone while 21.94 is low and 19.13 % is very low prone to landslides (Fig. 6).

Various investigators[1,3,29] have used ROC method to validate the output accuracy assessment. In this study, ROC is used to predict the true positive rate and false positive rate (figure 7). The efficiency of the model is determined by the AUC. The graphical plot attained ranges from 0 to 1. If the AUC ranges from 0.5 above based on the accurateness of the model, the model will be ideal. In this study the AUC is found to be 0.78 i.e. 78% precision and is reflected as satisfactory relative to susceptibility map.

Some photographs captured along the Mughal Road provide a proof of slope instability. Slides, rock falls, wedge failure are prominent in this area.

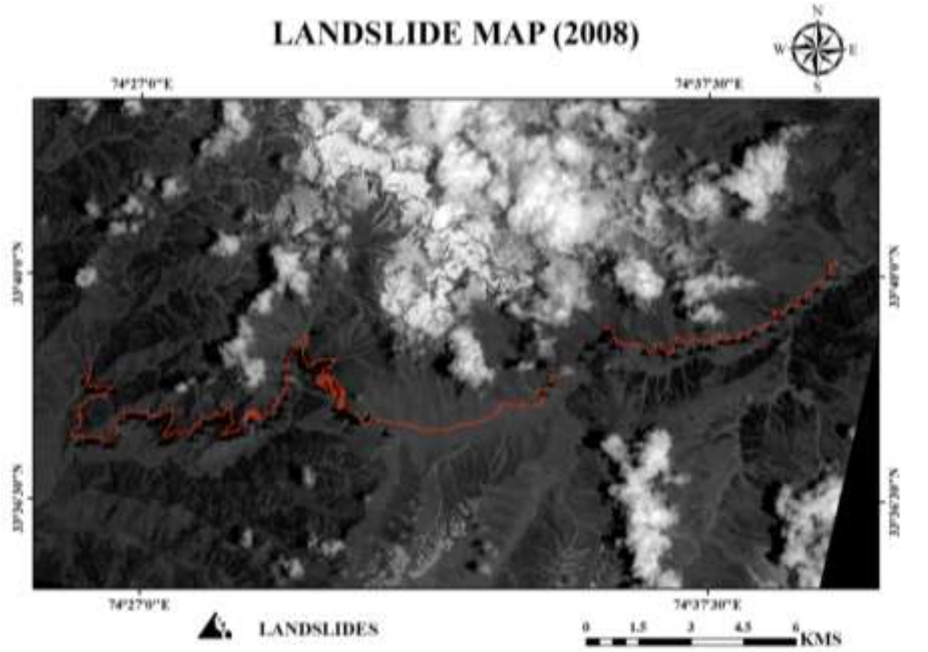


Figure 3: Landslide location for the year 2008

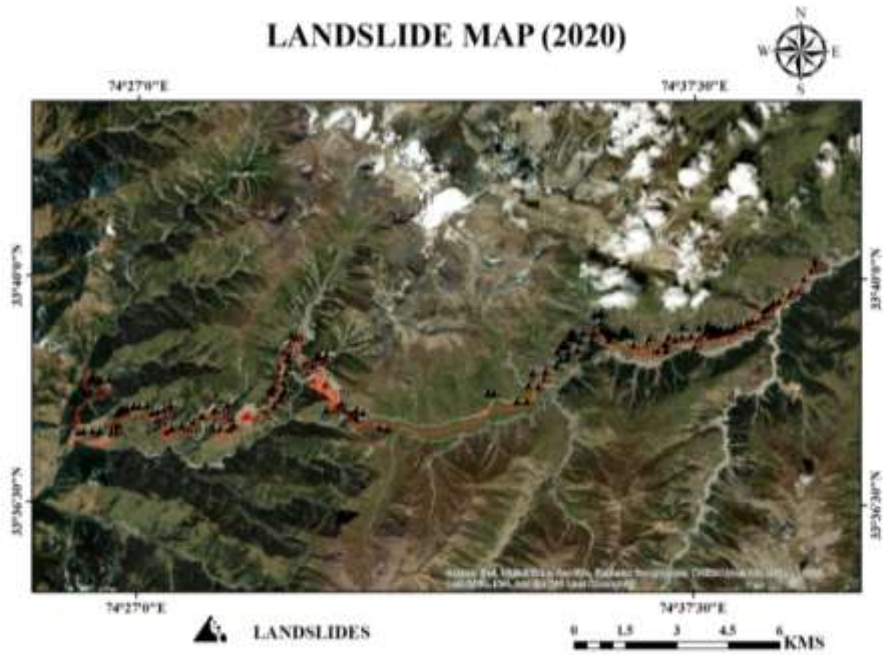


Figure 4: Landslide location for the year 2020

Table 2
Percentage area of Hazard zones

Hazard class	Number of pixels	Area %
Very low	3122305	19.13
Low	3579404	21.94
Moderate	4052974	24.84
High	3500179	21.45
Very high	2058237	12.61
Total	**16313099**	**100**

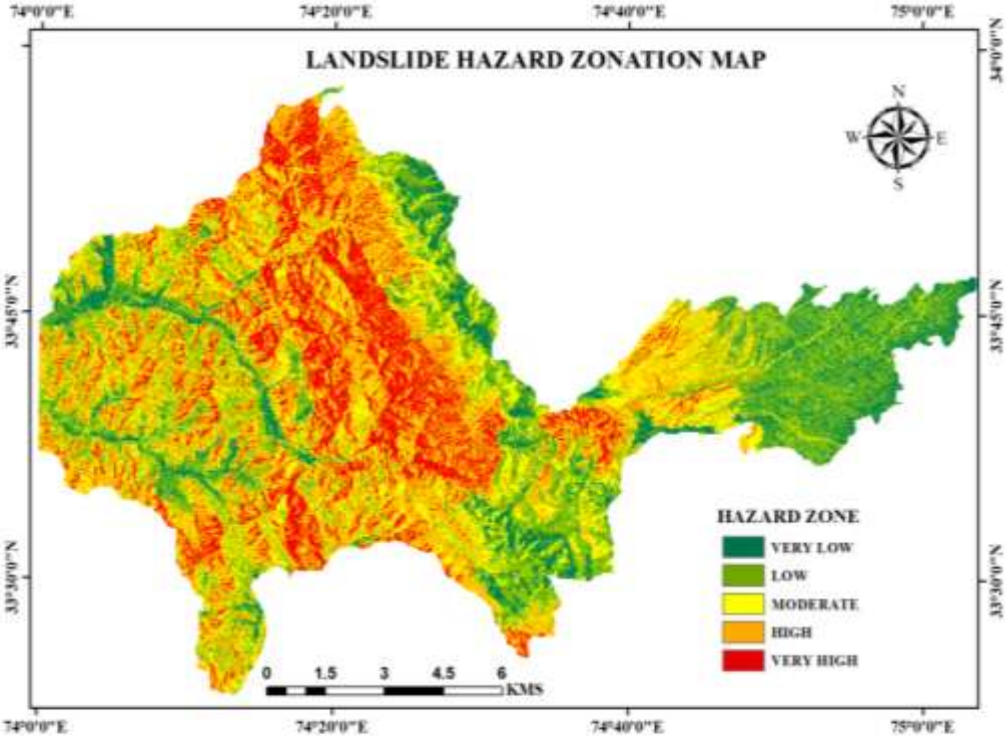


Figure 5: Landslide Hazard Zonation map

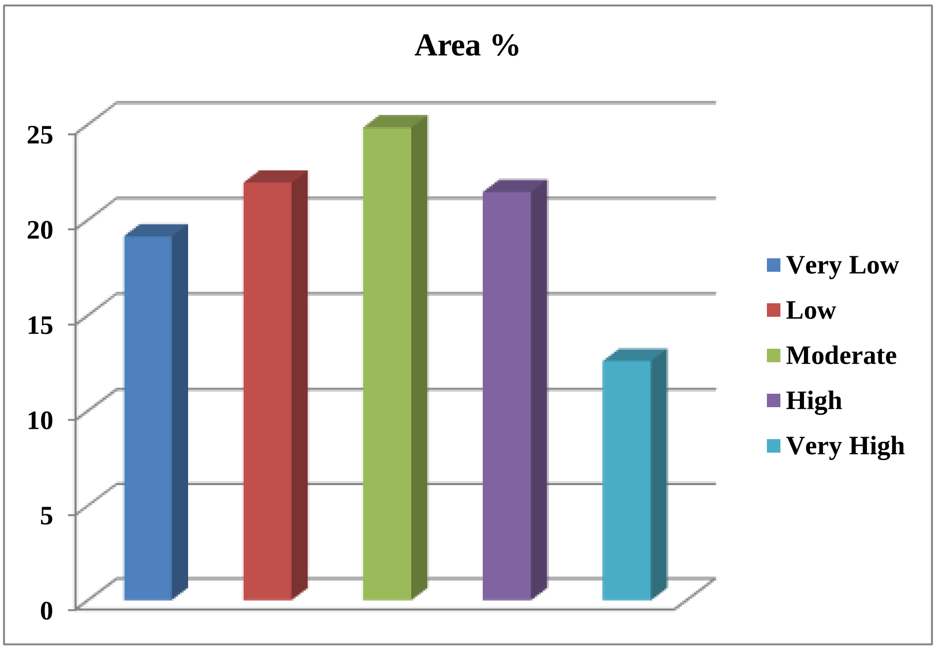


Figure 6: Graph of Hazard zone area in percent

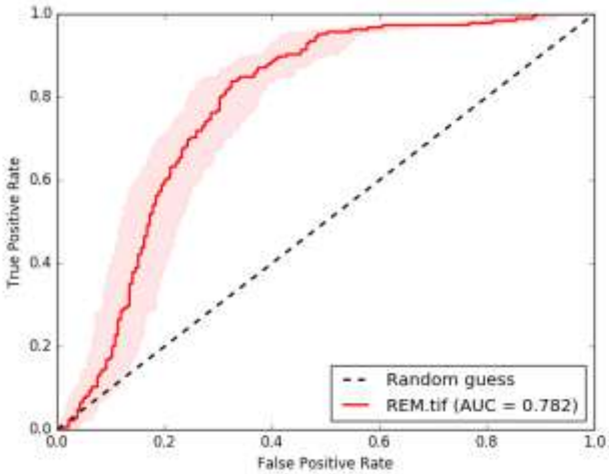


Figure 7: ROC of REM-LSZ map

Figure 8: Photographs showing the landslips along the Mughal road

Conclusion

The landslide susceptibility along the Mughal road was studied using the Relative Effect Method using 12 thematic layers as causative factors like lineament density, rainfall density, drainage density, NDVI, road density, LULC, lithology, geomorphology, geology, aspect, slope, elevation. Each factor was assigned with a relative effect value based on the equation1. Slope ranging from 33º- 40º appeared to be more prone to landslides. Lack or less vegetation is the main triggering point which leads to landslides along the road. Also in LULC, landslides appeared more to be on barren land. Also the highly dissected hills and valleys depict the positive values towards the landslides.

The diamictite, arenite with phyllite and ash beds and schistose quartzite, slate and gritty quartzite show positive values, which are highly prone to landslides. All the positive values from each causative factors made it possible to depict the total sum of the area that is hazardous to landslides.

The area was classified into five hazard zones as low, very low, moderate, high and very high susceptible zones. The validation curve has been generated and the predicted accuracy of 78% by ROC provides a good relation between REM output and landslide scars. This inventory will serve as a base map for the preparation of landslide geodatabase in detail and will serve for the economic and societal benefits as well.

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