Landslide Susceptibility Mapping along Mumbai-Pune Expressway, Western Ghats, Maharashtra Using Remote Sensing and GIS

Awadhesh Kant Soni[1], R.K. Rawat[2], Vaibhav Jain[3], Sunil K Panday[4]

[1, 2, 3, 4]Department of Applied Geology, Dr. Harisingh Gour Vishwavidyalaya, Sagar 470-003, India
[1]Email: *aman888soni[at]gmail.com*

Abstract: ***Mass movements are very common in the Western Ghats during and after the monsoon. The intensity of these movements is controlled by the degree of weathering of the rocks and rock joints, the amount of loose materials on the slope and altered/unaltered slope geometry. The rocks of Western Ghats are mainly Deccan Basalts of the Cretaceous Age which are weathered and jointed. The present studies are focused along Mumbai- Pune Expressway. It is the India's first expressway, which has six high-speed lanes and has a very heavy traffic load that crosses the hilly region of Deccan Basaltic terrain. The studied mass movements are located between Bhatan Tunnel (18.9141N, 73.17861E) and to Kamshet Tunnel (18.7294N, 73.5400E). This covers a linear distance of about 83 kilometers, in which ten spots have been identified. In every monsoon season, the expressway is suffered mainly by rockfall and subsidence problems which are being studied and mitigation for minimizing the loss of human life and property will be suggested after detailed field investigations. In general, the adverse geological, geomorphological, hydrological and engineering geological conditions might have caused the slope movements in the study area. An attempt is being made to investigate these problems observed along the expressway, that will incorporate a Digital elevation map, rainfall map, slope map, aspect map, landuse/landcover map, lineament (structure) map and drainage map which is prepared using ALOS PALSAR DEM on Arc GIS 10.5 software. The outcome of the present studies may be useful for controlling slope failure problems with similar conditions existing in other areas of India.***

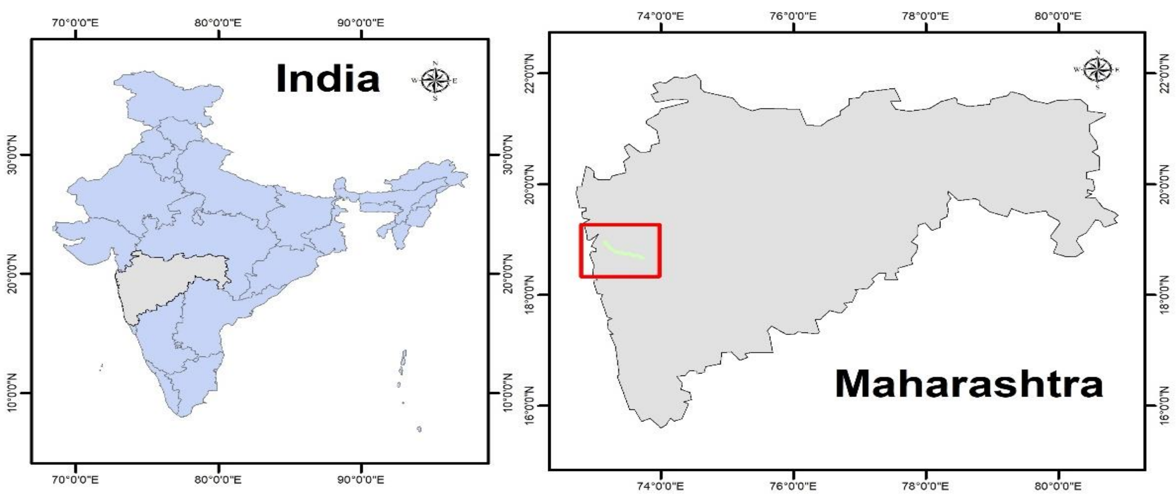
Keywords: Expressway, Deccan Basaltic terrain, Western Ghats, rockfall, subsidence, landslides, mitigation, Arc GIS.

1. Introduction

Landslides and subsidence are very common in Western Ghats during and after monsoon. The intensity of these movements is controlled by the combined action of geology, geomorphology, hydrology and engineering behaviour of slope forming material existing at the sites. Geologically, these failed slopes are made up of weathered and jointed Deccan Basalts of Cretaceous Age. After and during every monsoon season, various types of mass movements occur such as rock fall, subsidence, debris slide, debris flow and debris slump etc. In general, the adverse geological, geomorphological, hydrological and engineering geological conditions might have caused the slope movements along Mumbai-Pune expressway.

2. Study Area

The present study area is confined along Mumbai-Pune Expressway. This expressway is the India's first expressway, which has six high speed lanes and has very heavy traffic load which crosses hilly region of Deccan Basaltic terrain. The failure sites are located between Bhatan Tunnel (18.9141N, 73.1786E) to the exit point of Kamshet Tunnel (18.7294N, 73.5400E) on the Expressway.



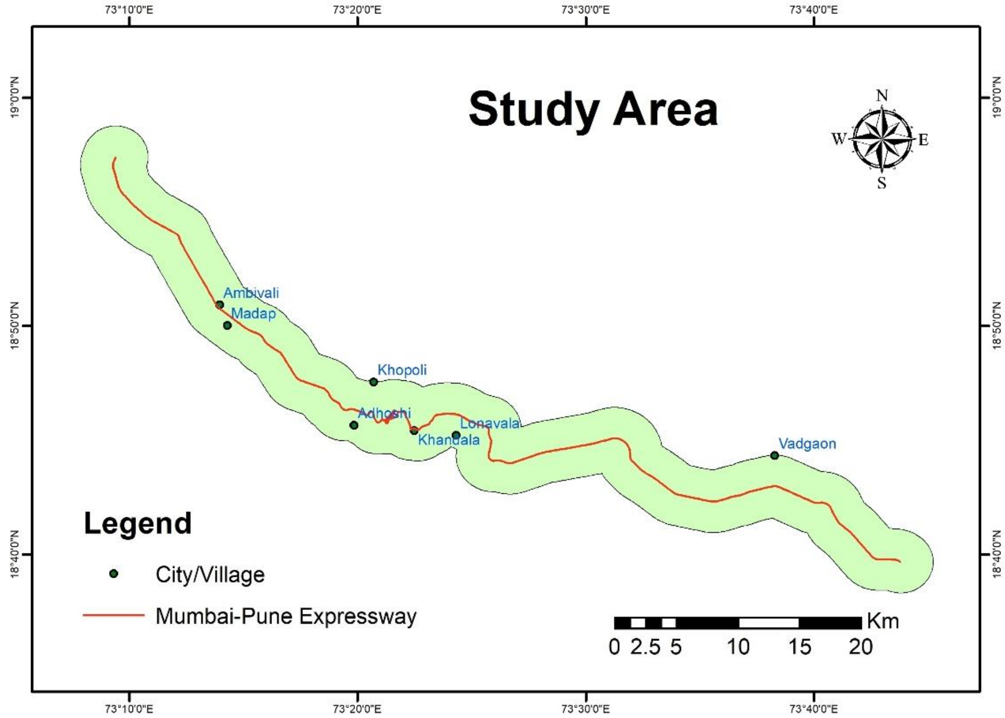


Figure 1: Location map of the study area

Geology of the Study Area: The study area is a part of Deccan Trap, which comprises huge accumulation of volcanic rocks, principally basaltic lava flows. There are 24 lava flows from the levels of valley floor to height of 986m. In the study area mainly two types of flows aa flow and pahoehoe flow are recognized. Out of 24 flows 13 flows are pahoehoe type and 11 flows are of aa type. Deccan Basalt rocks are of mostly five types viz. vesicular basalt, amygdaloidal basalt, fractured jointed basalt, massive compact basalt and weathered basalt. Surficial lateritisation also seen around the study area, specially near Karla village and Khandala. The country rock intruded by basic dykes which are trending in different directions. Doleritic sill has also been noted present in the area. Black cotton soil is mainly found in Deccan plateaus which is derived from black basaltic rocks. The black cotton soil possesses peculiar character such as, when it gets wet, it swells and become very sticky in nature while, when dry, it shrinks. Red boles are also present between two lava flows in the study region.

3. Methodology

Landslide hazard zonation

Landslide hazard zonation (LHZ) refers to "the division of the land surface into homogeneous domains and their ranking according to degree of potential hazard due to mass movement" (Krishnan, 2015). For the preparation of Landslide hazard zonation map, firstly different maps such as slope map, slope aspect map, drainage map, road map and landuse/landcover map have been prepared using ArcGIS software 10.5, along with the help of ALOS PALSAR DEM and Landsat 8 imagery downloaded by Earth Explorer USGS site and field investigations.

Data Collection

The landslide hazard zonation map has been prepared using satellite imageries, maps and toposheets (1:50,000 scale) acquired from Geological Survey of India and Survey of India. Various thematic maps have been prepared using ArcGIS 10.5 software and supported with GPS Coordinates collected from the landslide susceptible zones. The thematic maps are prepared on 12.5 meters resolution using ALOS PALSAR DEM and WGS 1984 UTM Zone 43N coordinate system.

Digital Elevation Modal: DEM is very important data for the preparation of landslide hazard zonation map. It gives the exact idea about elevation difference of the study area and plays a major role for the preparation of various thematic maps like slope map, aspect map, drainage map, contour map etc. For the present study these maps are prepared on 12.5 meters resolution for the better results.

Slope Map: Slope is a major causative factor of landslide. As the slope's angle increases the parallel component of gravity increases and the vertical component of gravity diminishes, in this way, the slope become more unstable. For the preparation of slope map the ALOS PALSAR DEM (spatial resolution 12.5 m) downloaded and used from Alaska Satellite Facility. The DEM clipped according to study area and slope map was prepared in ArcGIS 10.5 software. The slope map was classified into 5 classes 0 to 10, 10 to 20, 20 to 30, 30 to 45 and >45 classes shown by green, violet, yellow, orange and red colour respectively in the map (fig.). These classes represent the slope percentage in the study area.

Aspect Map: Generally, aspect map gives the idea about slope direction in the study area. For the present studies the prepared aspect map is divided into 10 categories, flat (-1), N (0-22.5), NE (22.5-67.5), E (67.5-112.5), SE (112.5-157.5), S (157.5-202.5), SW (202.5-247.5), W (247.5-292.5), NW (292.5-337.5) and N (337.5-360).

Rainfall: The rainfall and landslides are interrelated to each other. In fact, rainfall is an important trigger factor for landslide because most of the landslides occurred during heavy precipitation. For the present studies, the annual average rainfall data of the study area has been obtained from the centre for Hydrometeorology and Remote Sensing (CHRS), which is based on the PERSIANN-Cloud Classification. By the using of these data a rainfall distribution map of the study area was prepared.

Land Use/Land Cover: Landuse/Landcover map is prepared with the help of Landsat 8 Imagery downloaded from USGS Earth Explorer. For the present studies, the area is classified into 5 classes i.e., build up area, agriculture, vegetation, barren land and water bodies. Barren lands are comparatively unstable than the vegetated lands. The vegetation cover holds the loose soil and prevent from erosion and its movement. Comparatively speaking, forested lands are less likely to experience landslides than bare ones. The Mumbai-Pune expressway passes through hilly regions in which some hills are barren or without vegetation cover. Consequently, these hills are more prone to landslides. Thus, the landuse/landcover is an important criterion for preparation of landslide susceptibility map.

Lineament Map: Lineament/structure play a significant role in affecting the stability of slope. In the study area, joints/fractures are main control factor for landsliding activity. In order to understand the affect of structural features on landslide activity, the lineament map of the study area has been prepared which reveals that the area showing high density of the lineament is more prone to landsliding active compare to medium or low densities.

Drainage Map: Drainage Map is prepared with the help of digital elevation model and it plays a remarkable role in landslide hazard zonation mapping. The likelihood of a slope failure is always greater in areas with high drainage density. In comparison to a region with less drainage density, the area with higher drainage density has higher water pressure that can fail more easily.

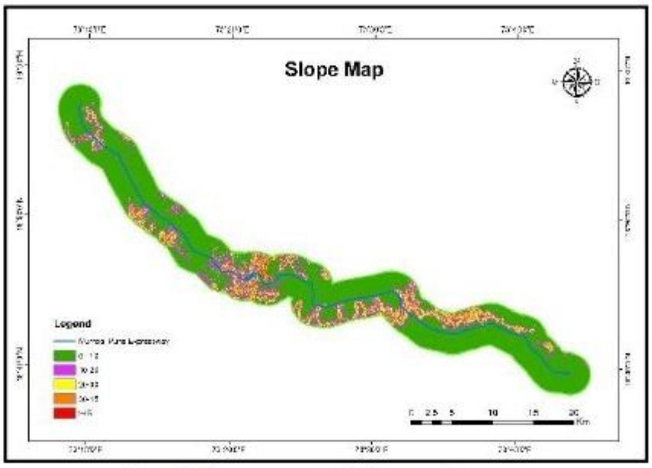


Fig. 2 Slope map of the study area

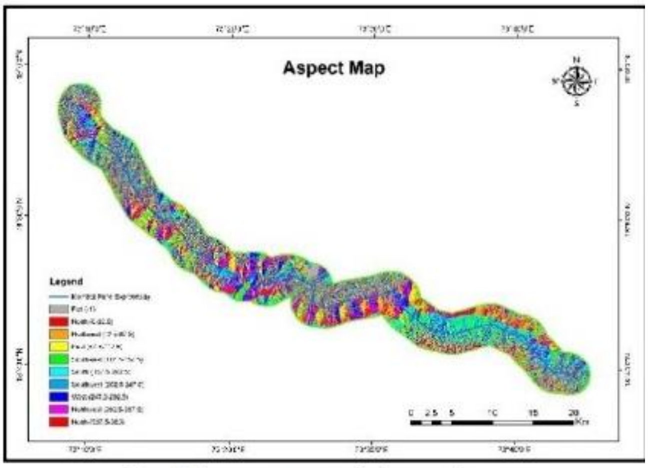


Fig. 3 Aspect map of the study area

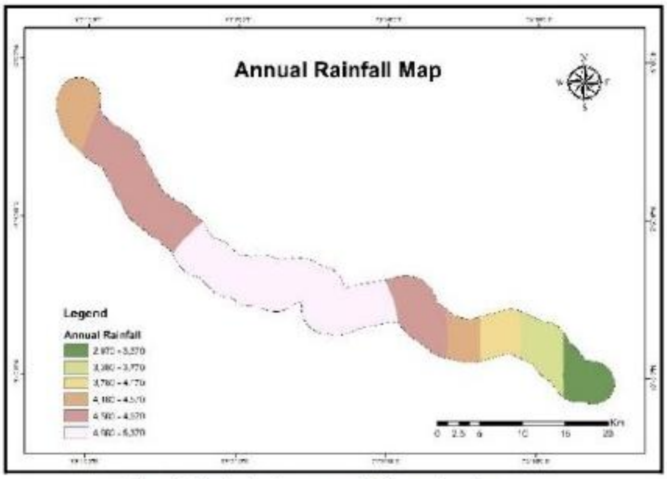


Fig. 4 Rainfall map of the study area

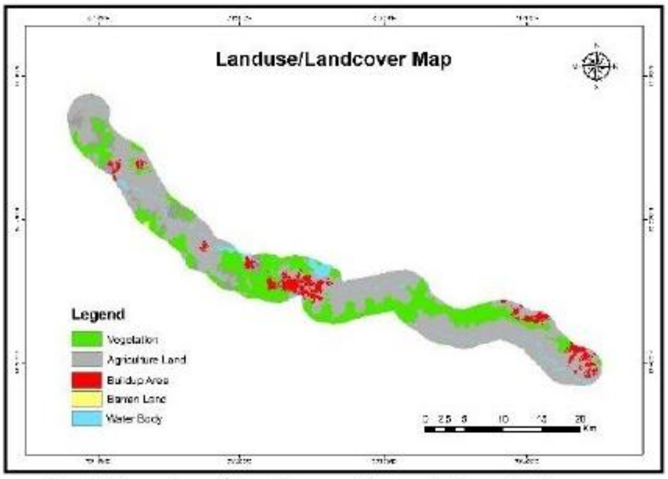


Fig. 5 Landuse/Landcover Map of the study area

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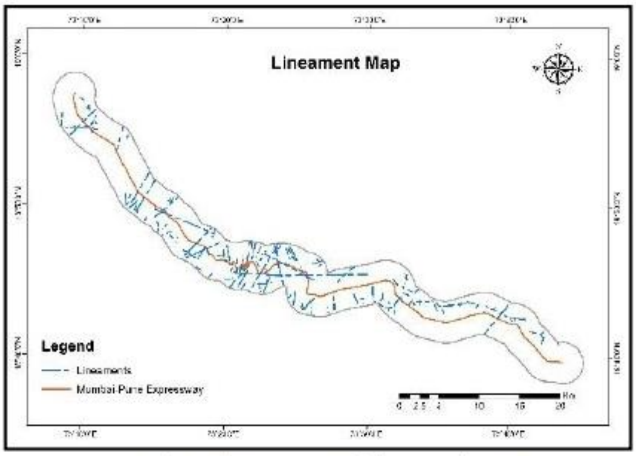

Fig. 6 Lineament of the study area

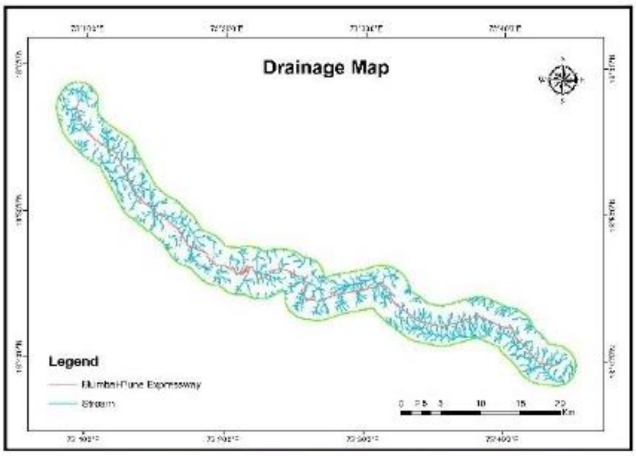

Fig. 7 Drainage map of the study area

4. Results and Discussion

Six factors were taken into account for preparation of landslide susceptibility map for the current study area such as drainage density, slope, elevation, lineament, land use/land cover and rainfall. Landslide susceptibility map was prepared using the weightage rating technique. Combining all control parameters and assigning separate weights to each variable resulted in the creation of the final landslide susceptibility zonation map, which was then divided into very low, low, medium and high susceptible zones. According to the characteristics of the present study area, the rainfall is given the most weightage since the majority of mass movements are associated with monsoon season, which is followed by slope, lineament, drainage density, lithology, and Landuse/Landcover.

High susceptible area is continuously in danger from landslides due to its extremely sensitive geology, especially during and after a particularly heavy rainstorm. This is due to the area's steep slopes, loose, unconsolidated soil, and the existence of evidence of recent or ongoing landslides. The region also includes tectonically vulnerable areas. It also includes areas where human activity, such as road cutting, tunnelling etc. is common. No activity that is caused by people is advised in the high susceptibility zone because of how vulnerable it is to landslides.

Medium susceptible region contains areas with a modest slope, a moderate amount of flora, and generally compact rock. Although there may be steep slopes in this location, they are less susceptible because of the direction of the bedrock, the absence of loose material on top, and the absence of human activity.

Low susceptible section includes areas where it is typically improbable that the interaction of several control settings may have a negative impact on the slope's stability. The vegetation is relatively dense, and the slopes are typically less than 25°. This area is mostly limited to places with little or no anthropogenic activity. Regarding the risk factor, there is no evidence of instability in this area, and mass movement is not expected unless significant changes take place. Despite the fact that some places' lithology may include soft rocks and debris from the soil below, slope failure is unlikely due to the slope's low aspect.

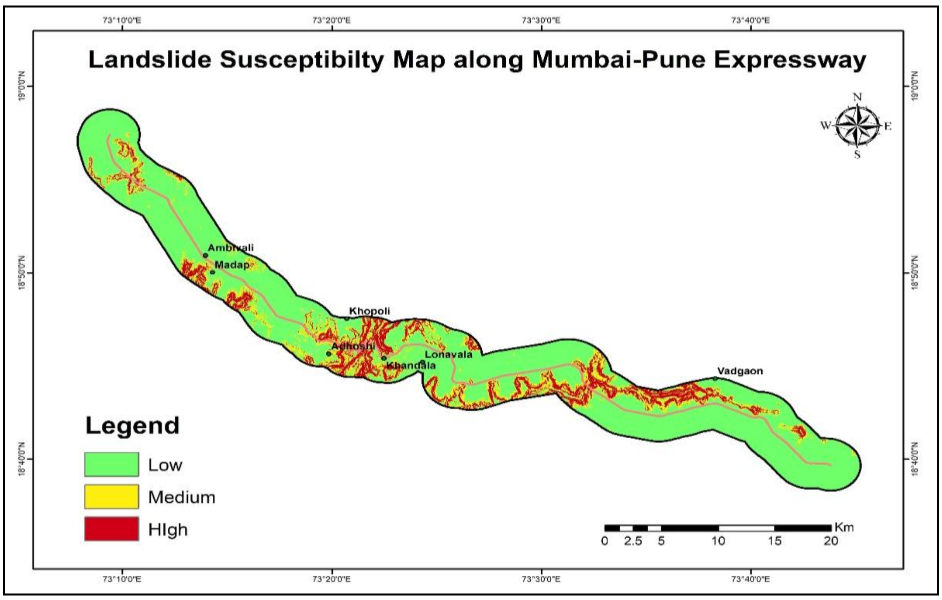

Figure 8: Landslide Susceptibility Map

5. Conclusion

It is evident from the studies that factors like landuse/ landcover, rainfall, slope, lineament, and drainage density are crucial in initiating landslides. As per the current analysis and the landslide danger index, rainfall comes in first place among the conditioning factors, followed by structures, lithology, slope, LU/LC, and drainage density. Three sensitive zones—low, medium, and high, each accounting for 74%, 14%, and 12%, has been identified. The process for landslide susceptibility mapping includes creating thematic information layers, merging spatial data, and validating results. The investigation shows that the GIS application is very beneficial for the creation of theme information and their sophisticated spatial examination of data. The present study helps to identify vulnerable zones for the mass movements and which can be suitable remedial measures like shotcrete, removal of unstable or loose materials, by making proper drainage channels.

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