# Landslide hazard zonation mapping and debris flow modelling in Nainital, Uttarakhand

**Richa Vaid[1], Shovan Lal Chattoraj[2], Sameeksha Mishra[2], P.K. Champati ray[2]**

[1]Symbiosis Institute of Geoinformatics, Symbiosis International University, Pune, Maharashtra, 411016, India

[2]Department of Geosciences, Indian Institute of Remote Sensing, Indian Space Research Organization, Dehradun, 248001, India

Landslide is one of the most devastating natural hazards in the Uttarakhand Himalaya, India. Though it has many active and old hotspots, we have focused on Nainital district only in this study considering recent events and challenges. Although available literature exhibits many such case studies from this area, landslip and landslide events which took place, off late, remains to be one of the major burning issue in this area, albeit. Out of many landslide hazard zonation methods, it is felt appropriate to apply Analytical Hierarchy Process in this area which takes cues mainly from measurements through pair wise comparisons of causative factors and relies on the judgement of the experts to derive priority scales to enable stake holders adopting a multi criteria decision making approach. Many thematic layers were, hence, considered for this purpose which includes slope, aspect, hillshade, land use and land cover (LULC), normalised difference vegetation index (NDVI), lineament, geomorphology, geology etc. These raster inputs were derived mainly from high resolution multispectral, open source DEM and others ancillary data sets. Landslide hazard zonation map, thus produced, were successfully validated on the ground. This kind of map for the whole district holds promise for the stake holders to assess potential high hazard zones and plan to provide remedial measures and thereby supporting mitigation mechanism in case of any future potential hazard. However, considering that present day research in the field of landslides has evolved beyond hazard zonation map, it was decided to develop debris flow models at few critical but strategically important sites by numerical simulation technique. This debris flow models are mainly to be fed space-borne and ground based geological and geotechnical inputs. The simulated result provide spatial variation of different geophysical parameters like pressure, momentum, height and velocity in the affected run-out zone. These outputs provides crucial information on real time landslide hazard mitigation and support to development of early warning systems.

**Keywords**: Landslide inventory, AHP, Landslide hazard zonation, Debris flow modelling

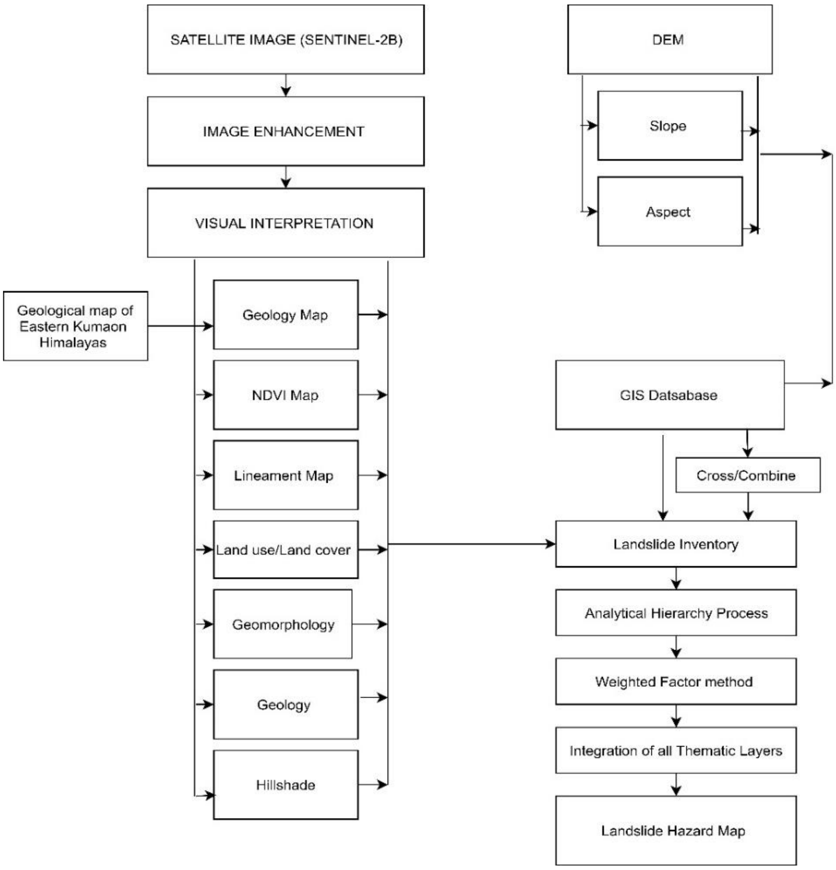
## Introduction

In the landslide studies, hazard usually defined as the likelihood of occurrence of potential damaging phenomenon (Crozier and Glade, 2005). Hazard analysis gives insight of damage occurrence with given period of time. With development of satellite observation technique and remote sensing, modelling theories combining data sources produce landslide hazard zones. Prediction also demand the comparison of previous landslides with set of environmental factors. Many direct and indirect methods have been practised in past for estimation. Analytical Hierarchy Method is an indirect method which overlay many layers so as to form hazard prone map. For analysis large amount of data is usually required.

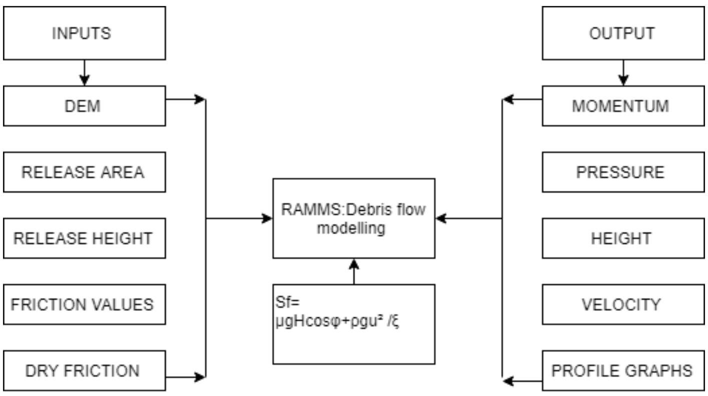
Debris flow is commonly found on mountainous areas and present a severe hazard due to their high mobility and impact energy In this study, Debris flow modelling was applied to calculate debris flow initiation of Baliyanala landslide. It is gravity driven force which is mixture of sediment, particles of various sizes and water flowing down to a confined channel shaped region down to its end. It assumes the shear formation. Debris flow model is a physical law of balance of mass and momentum in integration form either as hydraulic form or vertically integrated. Hydraulic equation depicts debris flow depth, volume flux and mass distribution. RAMMS helps in calculation of debris flow. It is based on Voellmy-Salm fluid flow continuum model on Voellmy-fluid flow law (Voellmy,1995) and defines the debris flow as hydraulic-based depth-average continuum model. The flow resistance is divided into dry-Coulomb friction and a viscous resistance turbulent friction. This study characterise and classify landslide hazard zones and also simulate debris flow modelling which provide identification of damage caused and mitigation.

## Materials and Methods

For landslide hazard zonation total 8 thematic layers were made namely slope, aspect, hillshade, land use/land cover, vegetation, geology, geomorphology, lineament were made. Landslide inventory map was also developed so as to know previously occurred landslide. All thematic layers were overlaid using Analytical hierarchy method (AHP). In AHP method first pairwise comparison is made between the criteria and alternatives. The weightages are given to the criteria and alternatives on the basis of the Saaty scale. The higher importance of criteria and alternative the higher the weightage given to it. After the weightages were calculated, the final averages are obtained after normalisation are taken as final input. These final inputs help in making decision when large number of choices are involved. Sentinel-2B and SRTM DEM data was used. Satellite imagery was corrected using Geometric and Radiometric correction.




**Debris flow modelling**- It is done with the help of Rapid mass movement software (RAMMS). RAMMS is based on Voellmy-Salm fluid flow continuum model on Voellmy-fluid flow law (Voellmy,1995) and defines the debris flow as hydraulic-based depth-average continuum model. The choice of the friction parameters requires careful calibration of the model by using reference information. It uses a single-phase model, it cannot differentiate between fluid and solid phases and the material is modelled as bulk flow. Many stimulations with diverse values for every input parameter were run to get desired results. Generated output included maximum momentum, maximum flow height, maximum flow pressure, maximum flow velocity and 2D-3D animations. It only requires two parameters to calibrate. The turbulent term controls the frictional behaviour when flow is moving rapidly and dry friction is used when the flow is slowly moving , letting the model to be approximately calibrated to observations of flow velocity and ending location of flow front. The RAMMS environment uses three dimensional: x and y is the directions of the mass movement flowing down topographic surface and elevation is given by z(x,y), which is perpendicular to profile. The gravitational acceleration vector three directions is g=(gx, gy, gz) and the time component is defined as t. the flow is move in unsteady and non-uniform motion and is characterised by two main parameters, which are the flow height and mean velocity. The initial height is determined by the user when defining the source area of the debris flow as a polygon. Alos Palsar data was used as DEM for the calculation.



**Results and discussion**

**Landslide Inventory-** Landslides are identified with the help of spectral characteristics, size, shape, contrast and morphological appearance. Mainly landslide is depicted by the contrast that results from spectral variation connecting landslide and its surrounding area. High resolution satellite imagery (Sentinel-2B, google earth landsat-8 data ) were used for landslide detection. The landslides were scattered throughout the area. The most common landslide is Debris flow situated near steep slope. The landslides have caused major damage in the study area.

**Land use/Land cover-** In study area specifically barren land, agriculture area, water, settlement, forest these classes have been validated with the help of BHUVAN WMS services. In Sentinel-2B satellite imagery all the classes were clearly identified. Supervised classification was used using maximum likelihood classifier. Forest occupied maximum amount of area which is 35.74% barren land occupied about 0.74%, agriculture occupied 194%, build-up/settlement occupied 1.35%, river bed/water occupied 4.52%.

**Slope Map** . Slope map in present study area is generated through DEM. In present study slope angle between 51-61 more susceptible to landslide. Massive landslide occur in high slope area. Slope area in present area was separated into seven classes ranging from lowest to highest. Lowest slope range between 0-9 degrees and highest slope range from 64-88 degrees

**Aspect Map** In the present study, ten classes of aspect has been divided namely flat, north, northeast, east, southeast, south, southwest, west, northwest, north. North and West slopes have maximum incidences of landslides compared to other aspect classes. The aspect map of the study area was generated with the help of DEM.

**Normalized Difference Vegetation Index (NDVI)-** Normalized Difference Vegetation Index (NDVI) map was generated from Sentinel-2B satellite imagery. The NDVI value was calculated using this formula $NDVI = \frac{IR-R}{IR+R}$. The value varying in between -1 to +1, near +1 indicate healthy vegetation cover and near -1 indicating unhealthy vegetation.

**Geomorphology** Four geomorphological units have been demarcated in the study are namely alluvial fans, hill range, mountain ranges, valley. Highly dissected and moderately dissected hill are more susceptible to landslide. Nainital is highly dissected valley as well as hills that causes massive landslide in this region.

**Geology-** The study area comprises of many lithological groups . Geology map contains lithology of surrounding area as well. Nainital area is covered mostly by Shales, Slate, List, Qzte, Black Shales. Lithology map was prepared with the help of AutoCad software and geology map was taken from Geological map of Eastern Kumaon Himalayas.

**Hillshade-** Hillshading is a technique for creating relief maps, showing topographical shape of hills and mountains using shading. It usually indicates relative slopes, mountain ridges but not absolute height. Hillshade map is prepared with the help of ArcGIS. Hillshade tool obtains the hypothetical surface by determining illumination values for each cell in raster. hillshade areas are where there is steep slope

**Lineament-** The lineament map shows the fractures, discontinuities, and shear zones. Map was made with help of visual interpretation of the Sentinel-2B satellite imagery. It is very important so as to show the linear features to weak zones of the earth surface. Lineament map was also validated with the help of BHUVAN portal and Google Earth. Rose diagram for lineament mawas made with the help of RockWorks16 software. Rose diagram help to show the direction of lineament. Most the lineaments in our study area face northeast and southwest direction.

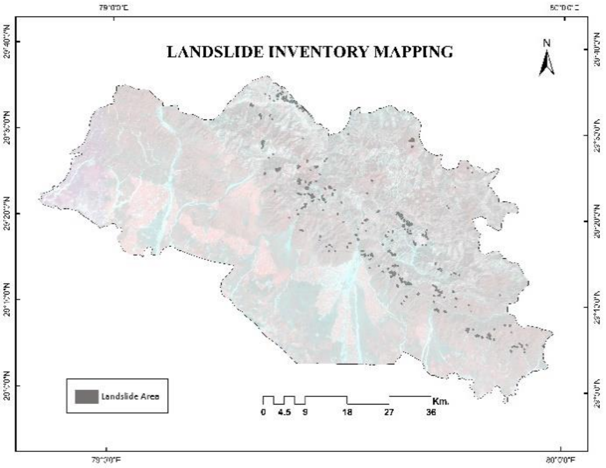



Figure 1: Landslide inventory map

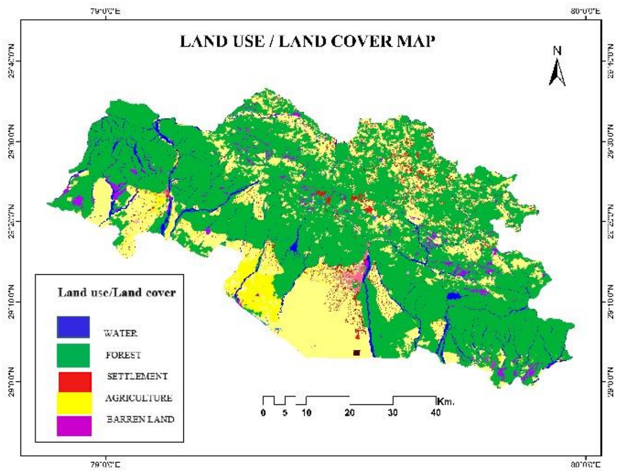



Figure 2: Land use/Land cover map

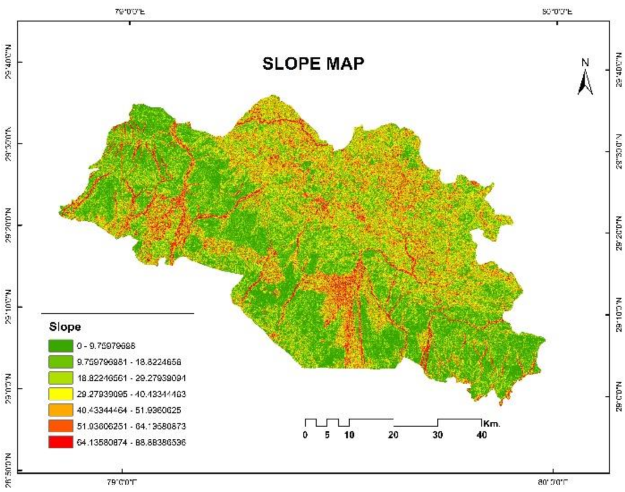



Figure 3: Slope map

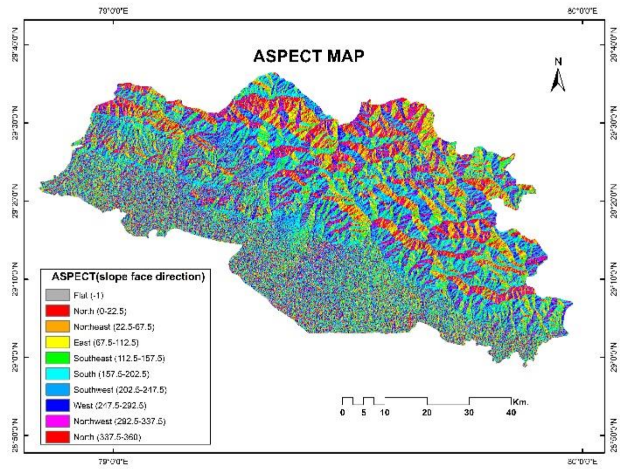



Figure 4: Aspect map

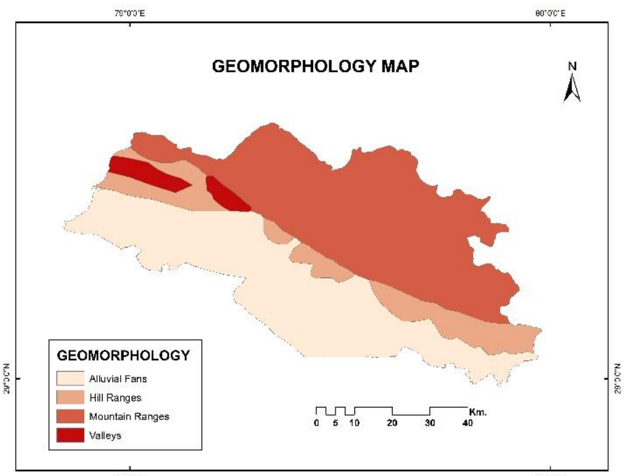



Figure 5: Geomorphology map

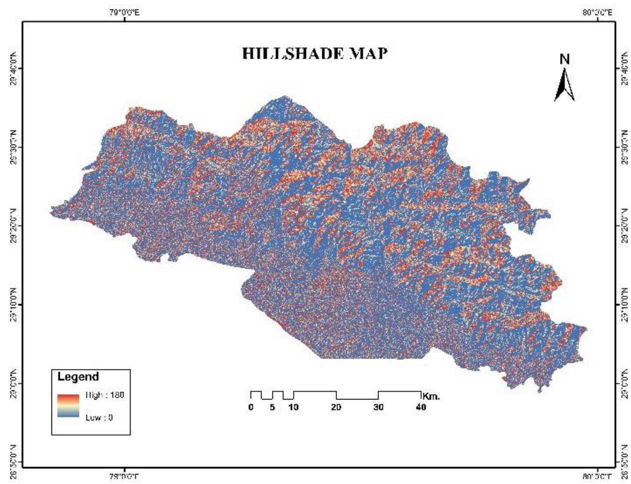



Figure 6: Hillshade map

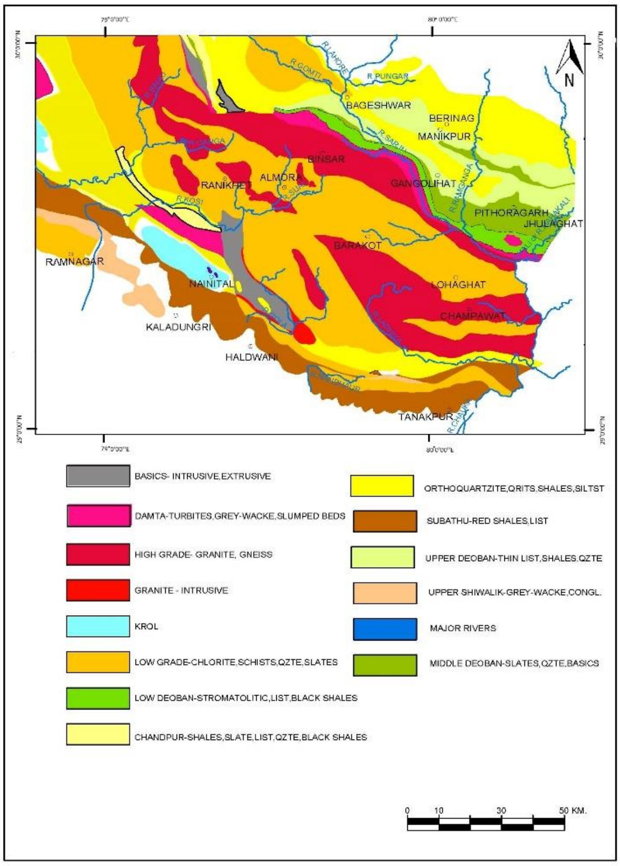



Figure : 7Geology map

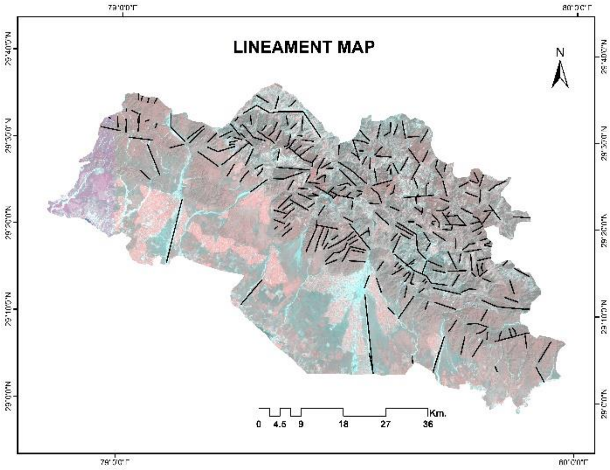



Figure 8:Lineament map

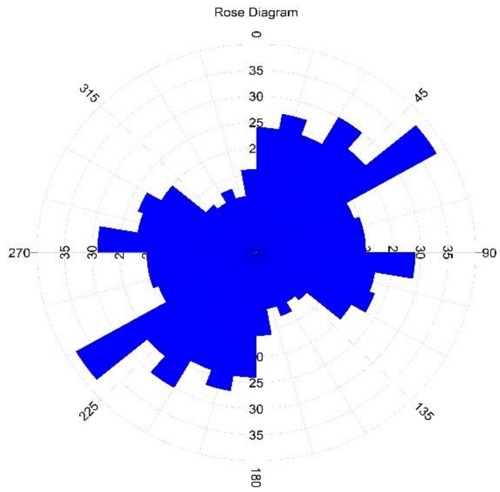



Figure 9: Rose diagram

**Landslide hazard zonation-** Landslide hazard zonation map mostly depends on the amount and excellence of the available data. There are four risk zones as identified from the map namely low risk, moderate risk, high risk, very high risk. The very high risk are mostly identified near the steep slope. Also high risk and very high risk area are delineated in north-eastern and north-western part of region whereas low risk regions are mostly found near western and southern region. The main reason which could be understood is the presence of dense vegetation, low slope area, less amount of lineaments and so on. From hazard map it is evident that Nainital region falls in high to very high hazard zone. Baliyanala is another place which falls in very high hazard zone. Almost half the region is in high hazard zone. Final landslide hazard map was then compared with landslide inventory map and result came to be satisfactory.

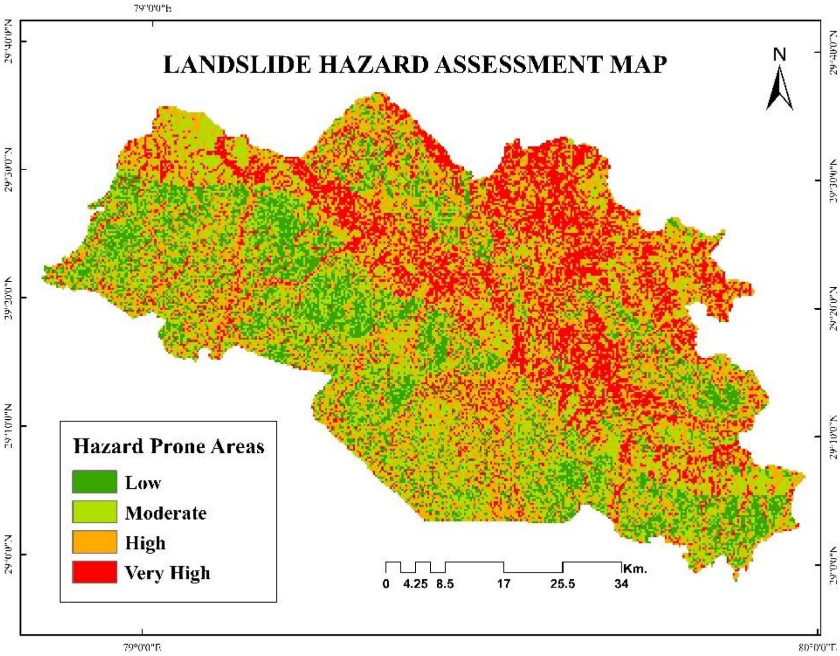



Figure 10: Landslide hazard zonation map

**Debris Flow Modelling-** RAMMS is a dynamic numerical modelling program simulating run-out mass movement in a three dimensional terrain. Flow height is important parameter of consideration from profile at any distance height of flow can be determined. It is helpful in calculation the amount of destruction it can cause. Flow velocity, pressure, momentum profiles indicate that amount of debris that will it the ground. RAMMS numerical simulation model is based on rheological character of the slope. The flow height is 12 m . The two main friction parameters are μ and ξ. The value taken for output for are μ and ξ were 0.25 and 2000m/sec. Frictional parameters were taken on basis of altitude, release area, volume of release area, type of terrain. Other parameters like density, cohesion, release height and percent of momentum were kept constant. In the simulation debris flow was unbranched till it reached it base. Two release areas were given in present study. The initial flow volume was 47470.00 $m^3$.

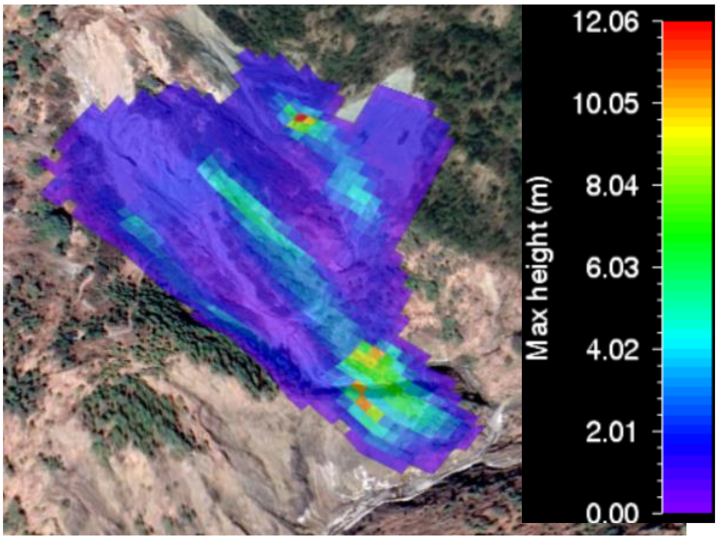



Figure 11: Maximum height

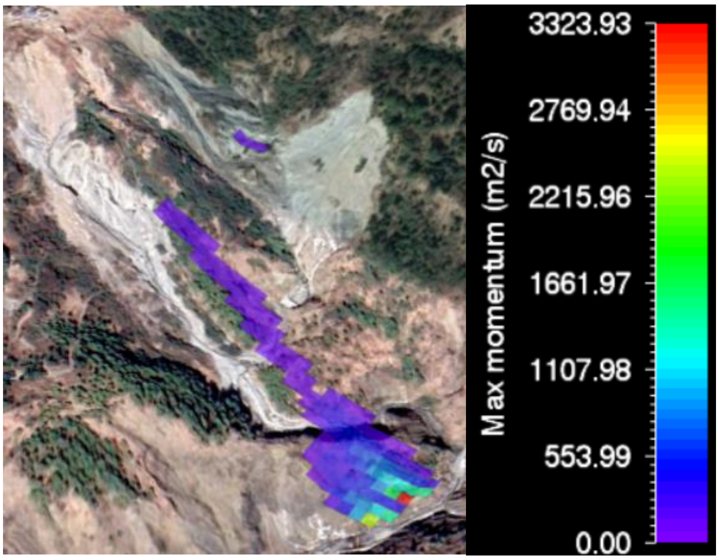



Figure 12: Maximum momentum

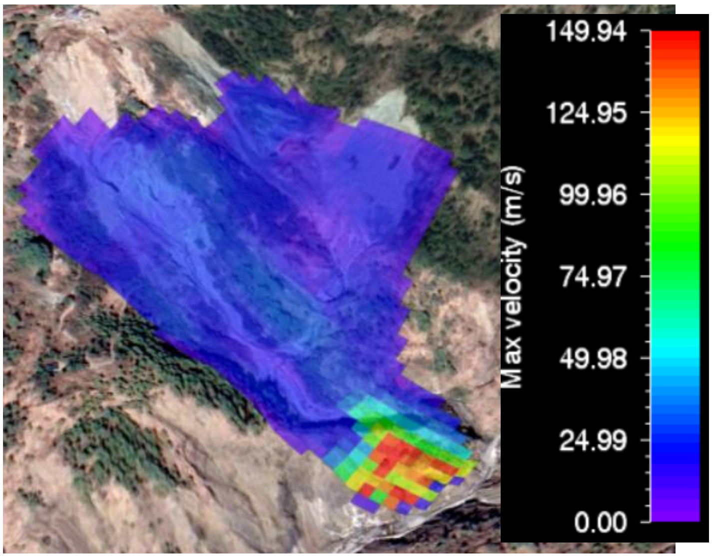



Figure 12: Maximum velocity

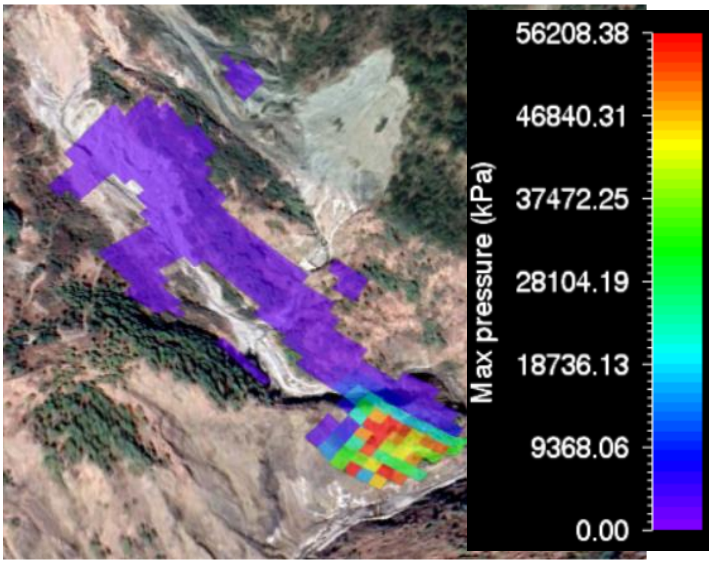



Figure 13: Maximum pressure

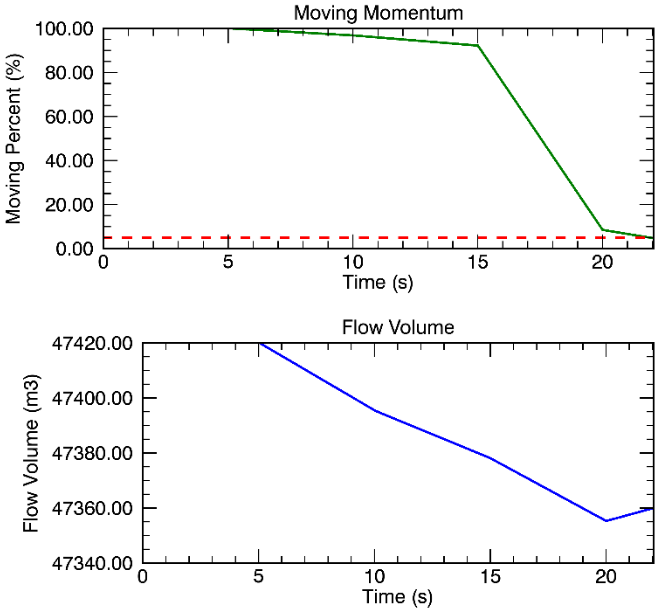



Figure 14: Profile graph of momentum and volume

**Conclusion-** In present study, Landslide hazard zonation map was made by overlaying eight thematic layers with help Analytical Hierarchy Process. Most of landslide occurred in steep slopes. The high risk zone was situated near north-eastern and north-western part of region. The AHP generated Landslide risk map gave a clear indication of the damages and effects caused in study area. And this can be easily validated with Landslide inventory map.

Attempt was made to model the runout of debris flow to evaluate the possible range of affected area of Baliayanala landslide spatially by numerical simulation techniques viz., RAMMS which can calculate the impact pressure. It gave information about height, velocity , pressure, momentum and 2D-3D profiles. The initial flow volume was 47470.00 $m^3$

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