“Delineation of Landslide Susceptible Areas in Karnaprayag, Chamoli District, Uttarakhand, India”

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Abstract:
Landslides are natural disasters that lead to widespread social disruption, property damage, damage of communication and infrastructure network such as roads, railways, telephone lines, cultivable lands, crops, plantations and loss of life. India has a history of unique and unparalleled catastrophes due to landslides. It is imperative to identify active or potential landslide locations while planning the alignment of a road, as it helps to avoid landslide prone stretches on the road. Through this paper, the author highlights the delineation of landslide susceptible areas in and around Karnaprayag, Chamoli district, Uttarakhand, India.

The main objective of the study was to delineate landslide prone zones via multi-spectral information resulting from remotely sensed data. Landsat 8 images were used for lithological, geomorphological, structural, lineaments, landuse/landcover and drainage mapping. DEM generated using Cartosat data was used and further slope and aspect was derived. Additionally, lineament and drainage morphometric analysis were carried out. These parameters are required for geospatial analysis to delineate landslide prone zones. These multi-layered databases were transformed into an aggregation of functional values to obtain an index of propensity of the land to failure. Since the information in the database is sufficiently representative of the typical conditions in which the mass movements originated in space and in time, to confirm the same, validation was carried out using different vintage of satellite imagery giving the same result. Consequently, the study area was classified into four different zones ranging from very high to low based on susceptibility to landslides. The outputs of this study can be utilized in future to mitigate the risk from landslides.

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Introduction

Landslides are one of the most hazardous phenomena with a relation to time and expansion. In the Indian subcontinent, especially in North-Eastern India, due to complex geological setups having a contemporary crustal adjustment, highly varying relief, heavy rain, heavy snow and ever increasing human interference make the Himalayan slopes highly landslides prone. The study of landslides has drawn global attention mainly due to increasing awareness of its socio-economic impacts as well as increasing pressure of urbanization on mountain environment (Aleotti and Chowdhury, 1999; Champati Ray and Lakhera, 2004).

In the last few decades, different methods and techniques for evaluating landslide occurrence have been developed and proposed worldwide (Hansen, 1984; Varnes, 1984; Hutchinson, 1995; Crozier, 1995). According to Carrara et al. (1998), these methods include inventory mapping (direct approach) and a set of indirect, quantitative methods, namely the knowledge-based (index), the statistical (data-driven), and the deterministic approaches. Despite the methodological and technical differences, most proposed methods consider that geological and geomorphological conditions of future landslides should be similar to those conditions that led to past and present slope instability. Therefore, mapping past and recent slope movements, together with the identification and mapping of the conditioning or preparatory factors of slope instability, are key to predicting future landslides (Carrara et al., 1998). The overlapping of landslide distribution and conditioning factors enable the dangerous zones to be defined, but not the return period or the probability of occurrence of the instability processes (Asté, 1991). In fact, most regional landslide hazard assessments provide a ranking of terrain units only in terms of susceptibility, not including the temporal component of the hazard. Hence, the susceptibility expresses the likelihood that a landslide will occur in an area based on the local terrain conditions (Soeters and Van Westen, 1996).

By nature, landslide susceptibility evaluation is a complex, multivariate problem involving extrapolation of local data to larger areas. Inherently this practice involves a high level of uncertainty (Crozier, 1995). Carrara et al. (1992) point out this uncertainty, mostly in landslide identification and mapping, in the susceptibility zoning procedure, and in the application of statistical models. In a later paper, Carrara et al. (1998) outlines the main factors that currently hamper the development of reliable quantitative models of landslide hazard assessments, namely the quality, quantity and relevance of the available information (data limitations), and the effectiveness and reliability of the available models (model shortcomings).

The landslide susceptibility assessment was carried out based on the combination of maps in a GIS environment, considering the knowledge of local experts (Mariana Madruga de Brito, et.al. 2015). The present paper deals with thematic data layer generation and its spatial analysis in a GIS environment for landslide susceptibility mapping in Karyaprayag of Chamoli district. Landslide occurrences are quite common in Uttarakhand. Additionally, the magnitude of damages caused every year in various parts of the state is also quite large.
**General Characteristics of the Study Area**

The study area falls on the route connecting the holy place Badrinath. The study area is bounded by 79° 22′30″E and 79° 30′E longitude and 30°22′30″N and 30° 30′N latitude. It is a well-connected with metalled road. It falls on the Chamoli district, Uttarakhand. Some of the important places nearby the study area include Pipalkoti, Badrinath, Auli, etc. The total area investigated is around 114.3 sq.km.

![Fig: 1 – Study Area](image)

Physiographically the area is essentially a highly rugged and mountainous terrain with an altitude varying from 400m to a maximum of 280m above the mean sea level. The presence of steep scarps, rugged slope faces, sharp ridges, deep narrow valley, cliff faces etc. testify that the area is under process of active erosion. The variation in relief is due to differential weathering & erosion of various rock types accentuated by the uplift of the Himalayas.

**Data Used and Methodology**

Landslide susceptibility mapping is predominantly a function of slope and combinations of slope, concavity/convexity and aspects next to these topography factors, geology, geotechnical properties, climate, vegetation and anthropogenic factors such as development and clearing of vegetation (Fell et al, 2008) are
other important factors. In this study, landslide susceptibility was evaluated by applying Information Value method.

In the present paper, various important factors were evaluated including Landuse / Landcover, Geology, Lineament density and slope. The geocoded satellite image (IRS LISS3) with spatial resolution of 23.5m was downloaded from NRSC Bhuvan site and digital elevation model of Cartosat with spatial resolution of 30m was used for the terrain modeling and hydrological modeling purpose. (For eg., for slope, stream order for drainage density etc. using ArcGIS & Image processing software). The adapted methodology for Landslide susceptibility mapping is shown in flow chart figure 2.

**Technology Used**
- ArcGIS
- ENVI

![Flow chart of the methodology](image-url)
The Information Value Method
Information value method is a statistical method for spatial prediction of an event based on the parameter and event relationship. It has been a very useful method for landslide susceptibility mapping by determining the influence of parameters governing landslides in an area and this method has been used by several workers (Yin and Yan, 1988; Jade and Sarkar, 1993; van Westen, 1997; Lin and Tung, 2003; Saha et al., 2005).

The information value $I_i$ for a parameter $i$ is:

$$I_i = \log \left( \frac{S_i}{N_i} \right) / \left( \frac{S}{N} \right) \quad (1)$$

Where, $N = \text{total number of data points (grid cells)}$; $S = \text{number of grid cells with landslide}$; $S_i = \text{number of grid cells involving the parameter and containing landslide}$; $N_i = \text{number of grid cells involving the parameter}$.

Negative values of $I_i$ mean that the presence of the variable is not relevant in landslide development. Positive values of $I_i$ indicate a relevant relationship between the presence of the variable and landslide distribution, the stronger the higher the score (Yan, 1988).

The total information value $I_j$ for a terrain unit $j$ is given by the formula:

$$I_j = \sum_{i=1}^{M} X_{ji} \times I_i \quad (2)$$

Where, $X_{ji}$ is value of parameter $i$, $j = 1, 2, \ldots, N$; and $i = 1, 2, \ldots, M$. $X_{ji} = 1$ if parameter $i$ exists in grid cell $j$ and $= 0$, if parameter $i$ does not exist in grid cell $j$; $M = \text{number of parameters considered}$. $X_{ji}$ is either 0 if the variable is not present in the terrain unit $j$, or 1 if the variable is present.

Therefore the relative susceptibility of a terrain unit to the occurrence of a particular type of slope. The above model was used to determine the information value of each category of the factors and the total information value of each grid cell of the area. The more the total information value the more is the degree of landslide susceptibility.

Result & Discussions

Lithological & Geomorphological Map
The lithological map of the study area is divided into two major formations, Pipalkoti and Chamoli formation. Pipalkoti formation consists of various types of limestone i.e. dolomitic limestone, banded limestone, crystalline limestone, slates & quartzite, showing north west attitude, while the Chamoli formation consists of quartzite & slates. The slates & quartzite are highly jointed & fractured & susceptible to sliding.

Geomorphic units encountered in the study area are Dissected structural hills, Dissected denudo structural hill, River terraces, Alluvial Fan, Flood plains etc. The Lithological and Geomorphological maps are shown in fig 3 and fig 4 respectively.
Fig: 3 – Lithological map of the study area

Fig: 4 – Geomorphological map of the study area
Slope Degree and Slope Aspect
Slope is an important aspect for assessing landslide hazard in the region. The slope at any point is gradient between the center & the neighborhood cell with maximum of minimum elevation, the steeper the slope, more liable it is to be unstable. Degree of slope is a value between 0 & 90.

The slope aspect map refers to the direction of the slope. It helps us to know the direction in which slope failure may occur in a region. The resultant map shows the direction from 0 to 360 azimuth with respect to north, westerly & southerly aspect (NW, W, SW, S & SE). these data indicates that the steep slopes with southerly aspect have comparatively lesser vegetal cover.

The Slope aspect and slope degree map are shown in fig 5 and fig 6 respectively.

Fig: 5 – Slope Degree map of the study area
Landuse/ Landcover

Landuse being a direct expression of the terrain condition gives an important indication regarding the slope instability. The nature of terrain & the diversity of the climate have influenced the landuse in the Himalayan terrain. The vegetal cover has a considerable effect on erosion & weathering intensities. Landslides are generally associated with areas having vary sparse vegetation (open scrub). Removal of the vegetal cover leads to accelerated erosion. Faster erosion & greater instability of the slope is found in barren rock or soil surfaces as well as in the sparsely vegetated areas. The Landuse/landcover is shown in fig 7.
Soil type & Rock Weathering

Soil type plays an important role to control or to increase the vulnerability of landslide. Clayey soil with finer material gets recharged with water & is prone to slide. Loamy skeletal soil having coarse fragments can be easily recharged with the drainages & slide. Similarly, in case of rock outcrop & sandy skeletal soil, angular fragments lose their bounding or cementing material due to drainages & are prone to slide.

In rocks, weathering due to temperature pressure gradient portion can loosen their cementing material & the bounding capacity decreases subject to sliding. External agencies play an important role to increase the rock weathering exposed along the surface.

The Soil type and Rock weathering map are shown in fig 8and fig 9 respectively.
Fig: 8 – Soil type map of the study area

Fig: 9 – Rock weathering map of the study area
**Landslide Map**
For the present study, all the landslides both old and active were traced from the imagery and were finalized after field check. This data was later used to check the accuracy of the final hazard map. The landslide map is shown in fig 12.

![Landslide Map](image)

**Fig: 12 – Landslide map of the study area**

**Distribution of Information Value and Zonation**
In the present study, information value method was used for data integration and generation of the landslide hazard map. For this method, different maps were crossed with the landslide maps and then the landslide density per unit class was be taken out, then the natural logarithms was used to find out hazard zones. The Landslide hazard map value thus created, was in a range of -0.78537968 to 1.60340466. A landslide hazard map was prepared by reclassifying the final active and old slide map into five classes namely very high hazard, high hazard, moderate hazard, low hazard, very low hazard.

<table>
<thead>
<tr>
<th>Sloe</th>
<th>Landslide Hazard Zones</th>
<th>Active Slide</th>
<th>Old Slide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very High Hazard Zone</td>
<td>1.60340 to 0.25205</td>
<td>1.07375 to 0.03545</td>
</tr>
<tr>
<td>2</td>
<td>High Hazard Zone</td>
<td>0.25205 to -0.72843</td>
<td>0.03545 to 0.00001</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Hazard Zone</td>
<td>-0.72843 to -0.37642</td>
<td>0.00001 to -0.37811</td>
</tr>
<tr>
<td>4</td>
<td>Low Hazard Zone</td>
<td>-0.37642 to -0.07853</td>
<td>-0.37811 to -1.04331</td>
</tr>
<tr>
<td>5</td>
<td>Very Low Hazard Zone</td>
<td>&lt; -0.07853</td>
<td>&lt; -1.04331</td>
</tr>
</tbody>
</table>
The landslide hazard zonation map based on active and old slide is shown in fig 13 & fig 14 respectively.

Fig: 13 – Landslide hazard zonation map based on active slide

Fig: 14 – Landslide hazard zonation map based on old slide
Conclusion

Landslide susceptibility evaluation involves a high level of uncertainty due to data limitations and model shortcomings. Additionally, the accuracy of susceptibility assessment is lower when different types of slope movements are considered as a whole, because those landslides may have different spatial incidence, and distinct threshold conditions concerning preparatory factors. This difficulty may be resolved by defining types of landslides prior to the susceptibility assessment. This procedure was applied in the landslide susceptibility assessment in the study area, using the Information Value Method.

Table 2
Active slide hazard zones

<table>
<thead>
<tr>
<th>Hazard Zones</th>
<th>Lithology</th>
<th>Geomorphology</th>
<th>Lineament Buffer</th>
<th>Slope Degree</th>
<th>Slope Aspect</th>
<th>Rock Weathering</th>
<th>Landuse/Landcover</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High Hazard Zone</td>
<td>Quartzite, Limestone slate, dolomitic limestone &amp; slate</td>
<td>Highly dissected denudostructural hill</td>
<td>Fault, Lineament, Thrust</td>
<td>45-60, &gt;60</td>
<td>N-W, N-E, W, N Facing</td>
<td>Moderate to very high</td>
<td>Forest blank, Grass land, degraded land, degraded vegetation, build up area</td>
<td>Loamy soil, Loamy skeletal soil</td>
</tr>
<tr>
<td>High Hazard Zone</td>
<td>Slate with quartzite band &amp; unconsolidated sediments</td>
<td>Alluvial fans &amp; Flood Plains</td>
<td>Fault, Lineament, Thrust</td>
<td>25-35, &gt;60</td>
<td>SW, W Facing</td>
<td>Moderate</td>
<td>Degraded vegetation, medium vegetation</td>
<td>Loamy soil, Clayey soil, Loamy skeletal soil</td>
</tr>
<tr>
<td>Moderate Hazard Zone</td>
<td>Crystalline marble, Thin band of slate, Dolomitic crystalline limestone slate &amp; quartzitic band, Dolomitic limestone &amp; Slate metabasics, unconsolidated sediments</td>
<td>Moderate dissected denudostructural hill</td>
<td>Fault, Lineament, Thrust</td>
<td>15-35</td>
<td>N-W, S-W, E &amp; N Facing</td>
<td>Low to moderate</td>
<td>Agricultual land, degraded vegetation, build up area</td>
<td>Loamy soil, Clayey soil, Loamy skeletal soil</td>
</tr>
</tbody>
</table>
Different types of landslides are not equally conditioned by the instability factors. Information value scores show that lithological unit is the main preparatory condition for rotational movements, while translational movements are mostly conditioned by concordance between the slope and dip of strata. Finally, shallow translational slides have the strongest spatial correlation with slopes with gradients higher than 25.

Landslide susceptibility evaluation and prediction deals with the spatial component of hazard, and has as a key objective to answer the question: Where will future landslides occur? Research on the spatial probability of landslide occurrence is critically important to the public administrations’ responsible for civil protection, urban planning and environmental management. In any event, different types of landslides neither have the same magnitude nor equal damaging potential. In study area, the deeper and larger slope movements (rotational and translational) may produce serious damage to properties and structures, while shallow translational slides are only responsible for minor road disruptions. Furthermore, the technical strategies to mitigate landsliding also depend on landslide typology. These are additional reasons to discriminate between different types of slope movements when assessing landslide susceptibility and hazard.

The landslide susceptibility assessment considering landslide typology needs to be transferred to decision makers who should implement landslide loss-reduction strategies, in order to reduce the likelihood of occurrence of damaging landslides and minimize their social and economic effects.

**References**


