"RS AND GIS BASED SLOPE STABILITY ANALYSIS USING WEIGHTED SUM METHOD FOR PART OF HIMACHAL HIMALAYAS, INDIA"

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Abstract:

Landslides are one of the most common natural hazards in the Himalaya terrain, causing widespread damage to property, infrastructure and human lives, almost every year. Appropriate management measures taken at the right time reduce the risk of potential landslides. This is the rationale behind taking up the research topic on the landslide. The present research work attempts to carry out LHZ studies in the part of Sirmaur district, Himachal Himalaya. It uses Weighted Sum Method of Qualitative Approach for Slope Stability Analysis. The highlight of this work is the creation of Landslide Hazard Zone's map. This research work makes use of Remote Sensing data, Topographical Maps, Published Documents and field survey for preparing spatial data on 7 predictor variables, which are Geological, Geomorphological, Topographical and Anthropogenic in nature. It is assumed that the effects of earthquakes and rainfall are uniform in the study area due to its limited geographic extent. Hence these factors won't be considered for analysis. It demonstrates the use of raster based GIS data for spatial analysis. Thus, the present research work establishes LHZ procedures in a landslide prone area.

Introduction

Landslides are a major problem in mountainous regions such as the Himalayas, Nilgiri Hills, Western Ghats and Northeastern region in India. Every year landslides cause large damage to infrastructure, property and sometimes loss of life. Large landslides in mountainous areas can result in landslide dams blocking river courses; it causes valley inundation upstream and can be subsequently breached by lake water pressure, thus cause the deadly flash flood or debris flow downstream. Landslide takes place most frequently in monsoon rains, as water is an important factor for initiating landslides. Inherent geological characteristics of the strata and the geometry of slope control the stability of slopes and in turn landslides. Active tectonic movements cause the instability and weaknesses across certain tectonic zones which are prone to landslides and other types of mass movements. Himalaya is one of the major landslide prone regions in India, which experience the landslide events and causes loss of property and human lives almost every year. The region of the present study i.e. Himachal Pradesh has witnessed many destructive landslide events in the past such as Spity valley landslide in September 2009, Landslides at Raison, Dobhi, Alu Ground, Rangri and Manali in February 2011, recurrence of such events cause the disturbances in post disaster relief, rescue, reconstruction of infrastructure. Redevelopment in such areas increases the burden on the state treasury. Mountainous terrains must have some good policies for planned development, highly reliable landslide hazard maps and landslide hazard mitigation strategy. For all these things the most important factor is the identification of potential landslide hazard area based on past events of landslides, geological, geomorphological and topographical conditions. The purpose of the present study is to prepare most reliable Landslide Hazard Zonation map, taking into account the geological, geomorphological, topographical and anthropogenic conditions. It is assumed in this study that the effects of earthquake and rainfall, which are the major triggering factors for landslide, more or less uniform in the study area due to its limited geographic area. Therefore these factors have not taken into consideration for LHZ mapping.

Objectives

1) Preparation of thematic maps on the basis of various causal factors of landslides e.g. geological, geomorphological, topographical and anthropogenic.

2) Landslide hazard assessment and its Zonation based on the contributing factors and existing landslides using the weighted sum method.

Location Map of the Study Area

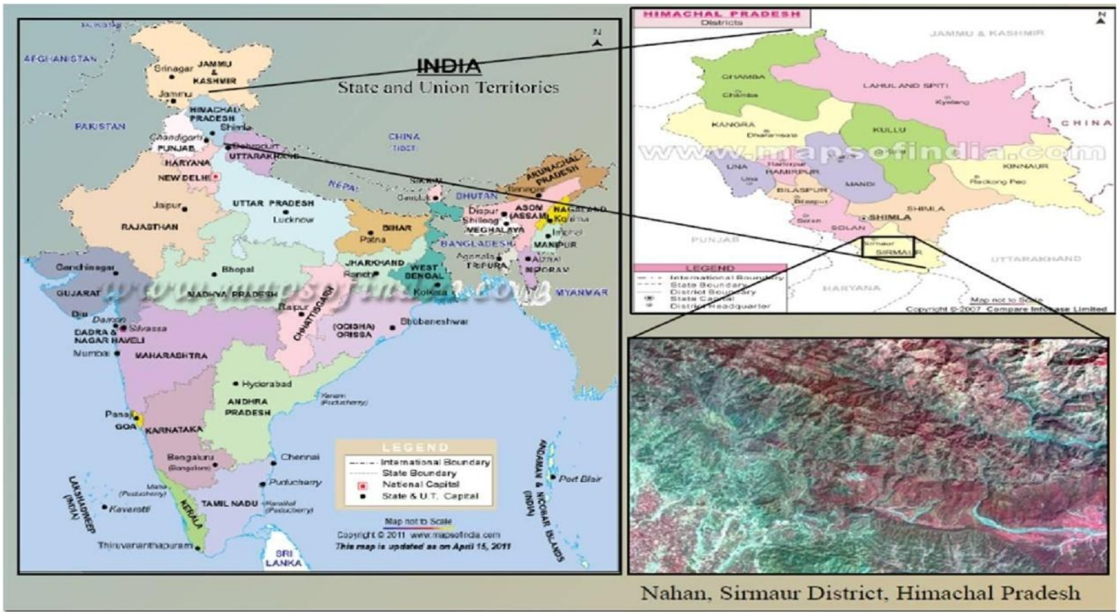

Fig. 1

Study Area

The selected study area is a part of Sirmaur district, Himachal Pradesh. It covers an area of 950 km^2 and is bounded between latitude 30^{0}30’00” and 30^{0}40’00”N as well as longitudes 77^{0}18’00” and 77^{0}33’00”E. The major township in the area is Nahan city, it is the district headquarter of sSirmaur district and very well known as the best designed city. Some major rivers flowing through the area, these are Giri River, its tributaries Jalal River, Jagar ka Khala, Khair ka Khala etc., Markanda River, Bata Nadi. The study is having the two distinct geological regimes; the Shiwaliks and the lesser Himalaya. It also has one of the most important regional geological structure; the Main Boundary Thrust (MBT), passing from southeast to northwest direction.

Data used:

Satellite remote sensing data is one of the major datasets used in the present work. Topographical maps of SOI and relevant geological maps from published literature have been referred. The details of the data used are given below:

Table 1 – Data used in the study

Data	Scale	Source
IRS P6 LISS III	23m X 23m	NRSC Data Center, Hyderabad.
IRS P6 LISS III	5.8m X 5.8m	NRSC Data Center, Hyderabad
Cartosat 1 PAN	2.5m X 2.5m	NRSC Data Center, Hyderabad
SOI Toposheet	1: 50000	Survey of India
Rupke’s Geological Map	1: 100000	Geological Survey of India .
ASTER DEM	30m X 30m	USGS online data center

Methodology:

In this study Weighted Sum method was used to produce landslie susceptibility map for the part of Sirmaur district. Following parameters were used as the cause factors of slope instability and landslides in the study area.

Lithology:

One of the important inputs into slope stability mapping is the information as well as the spatial distribution of various lithological units. In the Himalaya, due to the complex post-depositional tectonic disturbances and also due to the ruggedness and inaccessibility of the terrain, mapping of individual lithological units is very difficult. So, it is possible to prepare the lithological map with the help of published geological maps, taking the combination of various lithological units mapped as a single lithostratigraphic unit or individual lithological units mapped under various formations. In the present study, the lithological map has been prepared using the published geological maps (Rupke’s Geological Map) pertaining to the study area by grouping or rearranging geological units based on the most prominent or characteristics lithological unit in each formation. The geological units have been designated with the lithological classes according to the description given above.

Geological Structure:

The geological structures which are considered in the present study for slope stability analysis, are faults (thrust/normal faults), joints, fractures etc. The regional geological structures like thrust and faults and present in the study area have been mapped by earlier workers. In addition to the conformed thrusts and faults, there are many features such as faults, joints and fractures, which have drawn only from remote sensing data. The traces of features appear as linear to curvilinear entities on satellite images, depending on the topography and attitude of the structure. These are commonly designated as lineaments.

In the present study, the lineament have been interpreted on standard FCC prepared using merged image of IRS P6 LISS IV and CARTOSAT1-PANA images. The geological structures of the study area nsisting of the confirmed thrust/faults and the inferred faults, fractures and joints.

Slope:

Surface topography controls flow sources, flow direction and soil moisture concentration is an important factor limiting the density and spatial extent of landslide (Ayalew and Yamagishi, 2005). So it is necessary to use information on elevation, slope, slope aspect, relief etc.

Slope is a parameter that is closely associated with the elevation. It can be defined as the rate of change of elevation over a surface. In tectonically active regions with incising bedrock channels, hill slopes steepened above a threshold angle are rapidly denuded until the slope is brought back down to the threshold angle (Carson and Petley, 1970). Because precipitation affects the slope stability through its control on pore pressure, Car son (1976) proposed that slope angle may adjust to climate through landsliding. This suggests that there is an association between the slope angle and the slope stability. Slope is one of the most important geomorphic factors for shallow mass movement processes (sidle et al., 1985). Gentle slopes are expected to show lesser tendency for slope failure. At the same time steep natural slopes having outcropping bedrock may be more prone to rock falls and similar kinds of slope failure rather than shallow landsliding (Lee and Evangelista, 2005). For the present study, slope has been calculated using the DEM as the input. The slope function available in spatial analyst tool in ArcGIS, ArcMap software has been used for calculating the slope. In the study area, the slope values vary from 0^0 to 88^0. The flood pain area and the nearby fluvial terraces show the lowest slope values in the study area. Being one of the significant controlling factors of slope stability, the categorization of this continuous variable should incorporate its sensitivity towards slope failure. This means that a small number of slope classes will overlook the influence of some particular range of slope values. At the same time, a large number of classes will increase the complexity of the statistical analysis. The slope values have been classified into eight classes.

Slope Aspect:

The morphological parameter that complements slope is its aspect. Aspect can be defined as the prevailing direction of slope of a surface. It is expressed as the angle between slope direction and the N direction, measured clockwise from N.In multifaceted landscapes, which usually are the case with natural landforms, the solar insolation varies according to the slope aspect and thereby creates varying microclimatic condition in an area. The microclimatic variation influences the soil moisture and erosion potential and hence controls the slope form. The equator facing slopes is hottest and driest while pole facing slopes are cooler and moister (Wilkinson and Humphreys, 2006). In the northern hemisphere, S facing slope receives more direct sunshine and experiences higher evaporation loss from the surface (Thornbury, 2002). The slope aspect also influences the rate of weathering of the rocks by inducing differential effects on the rocks exposed in different aspects and thus indirectly influencing the stability of the slopes.In the study area, the slope aspect has been calculated from the DEM using spatial analyst tool in ArcGIS, ArcMap software. In the present study, the slope aspect values, which range from 0 to 360^0 have been classified into 8 classes of 45^0 intervals.

Drainage:

In order to incorporate the influence of drainage in the slope stability analysis, it has been decided to utilize the distance to the drainage information. It has been computed on a cell-by-cell basis, using a 25 m grid. For each cell, the shortest distance to the nearest drainage segment has been calculated and this has been given as its value.

Land Use/Land Cover:

The land use/land cover condition of the area is another factor which influences the stability of slopes to certain extent. The term land use relates to the human activity associated with a specific piece of land. Land covers relates to the type of feature present on the earth such as forests, water bodies, grass lands etc. The land use characteristics of the area is a reflection of the human interference, which effectively and productively utilizes the land or causes the degradation of the land (Lillesand et al., 2005). The presence of vegetation in the form of dense forests helps to increase the shear strength of the soil due to root-induced cohesion. Land use mapping may also reveal the presence of landslide areas, which usually are susceptible to slope failures in the future. Further, the land use/land cover information will enable the planners and the administration to take appropriate landslide hazard mitigation measures. In the present study it has been decided to carry out the land use/land cover classification using the IRS P6 LISS IV data as the objectives is to get the spatial distribution of the broad land use/land cover categories, rather than going into the very detailed mapping for local supervised classification. Supervised classification using the maximum likelihood procedure has been adopted for the preparation of land use/land cover map.

Road:

The construction of roads along the slopes of hilly terrains causes destabilization of the terrain due to multiple factors such as removal of slope support, reduction of the rock mass strength due to the enhancement of the planes of weakness in the rocks or creation of new discontinuities resulting from the blasting etc. the road network in the study area has been taken from the SOI toposheets and are new roads which have constructed after the period of mapping of the toposheets are updated with the merged PANA and LISS IV data. The distance to road has been calculated using a 25m grid and each cell has been assigned a value, which is the distance to the nearest road segment. The grid data of distance to road (figure 4.7) has a maximum value 7565m. The influence of the road cannot extend to distance of the order of 5.5 km in creating slope instability.

Analysis:

The main objectives of the present work

are to study the landslide hazard in the study area, to categorize the area into different hazard classes using qualitative methods of LHZ for their accuracy of slope failure susceptibility prediction. Due to the limited geographic extent of the present study area, the variation of the climatic conditions is narrow and the triggering factors, which strongly affect the temporal dimension of slope failures, are assumed to be a uniform influence over the study area. Hence, in the present study, landslide hazard and landslide susceptibility are used for implying the same meaning; the probability of slope failure in the spatial context. The LHZ mapping of the study area, using qualitative methods. This method is strongly dependent on the experience of the surveyors, but it is the only practicable approach for landslides caused by different mechanisms. The layers were weighted with indices due to their importance iteratively and were combined into a landslide susceptibility map. Landslides in the Himalayan terrain have varying controlling factors. It is very difficult to develop a generalized regional model to successfully predict the landslide hazard across the Himalaya. In the present study, Slope Stability Analysis has been attempted using the Weighted Sum Method.

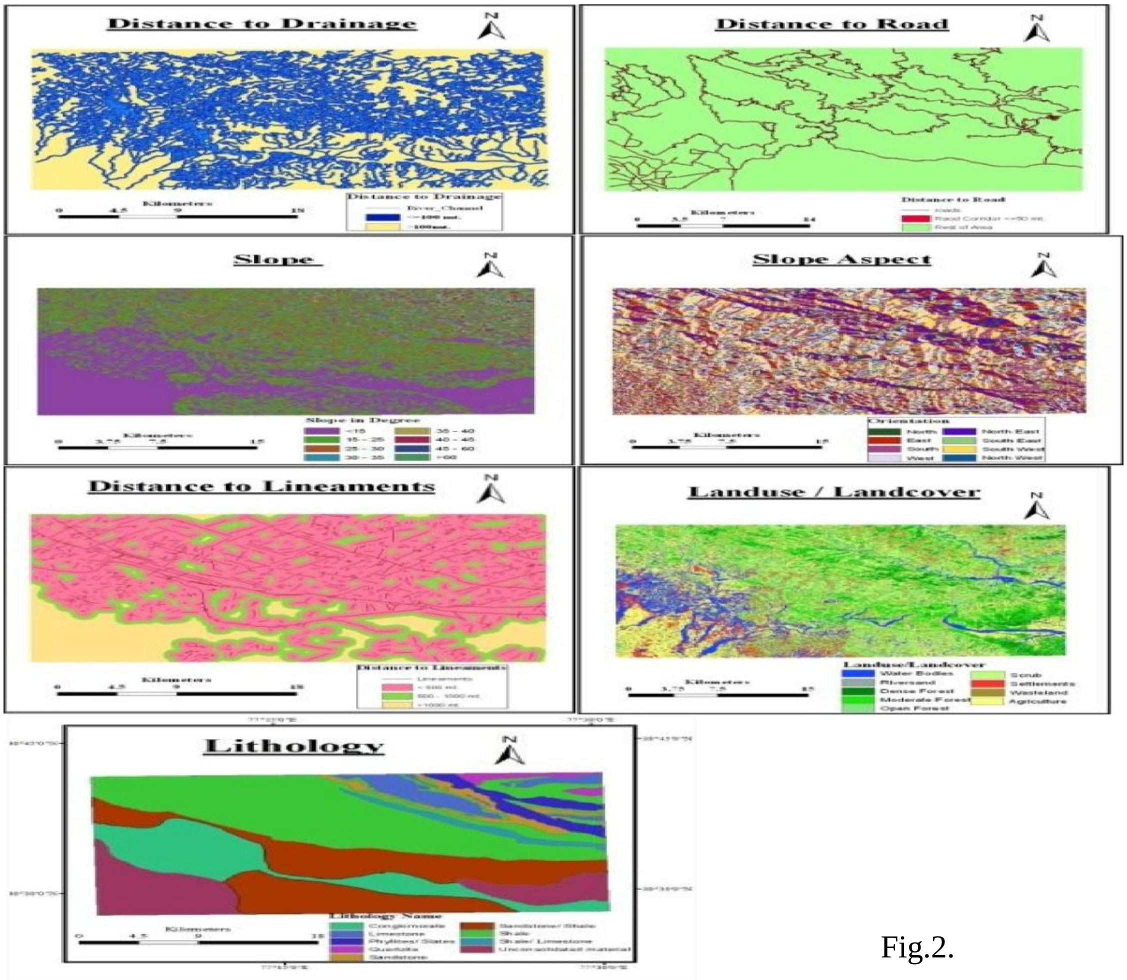

Fig.2.

Analysis using weighted sum method

A weight function is a mathematical device used when performing a sum, integral, or average in order to give some elements more "weight" or influence on the result than other elements in the same set. They occur frequently in statistics and analysis, and are closely related to the concept of a measure. Weight functions can be employed in both discrete and continuous settings. In order to prepare a qualitative landslide hazard zonation map weighting and rating system has been adopted in this study. It is based on the relative importance of various causative factors. An ordinal number (0-9) is given to each layer in terms of its relative importance. Similarly, each class of the data layers has been given an ordinal rating from 0 to 9. Table 2 describes the weight and rating given to each data layer and their classes respectively. These weight and rating values have been assigned using expert defined weight and rate for each parameter and each class.

Sl. no.	Parameters	Rate	Category	Weight	Total
1.	Slope	9	$<15^{0}$	2	18
			15^{0}-25^{0}	3	27
			25^{0}-30^{0}	5	45
			30^{0}-35^{0}	8	72
			35^{0}-40^{0}	9	81
			40^{0}-45^{0}	8	72
			45^{0}-60^{0}	7	63
			$>60^{0}$	5	45
2.	Lithology	8	Unconsolidated material	8	64
			Conglomerate	6	48
			Sandstone/Shale	7	56
			Sandstone	7	56
			Shale	6	48
			Limestone	5	40
			Phyllites/Slates	3	24
			Shale/Limestone	4	32
			Quartzite	2	16
3.	Distance to Lineament	7	<500 m	9	63
			500-1000 m	6	42
			>=1000 m	3	21
4.	Distance to Drainage	6	<100 m	4	24
			>=100 m	2	12

5.	Landuse	5	Water body	2	10
			Riversand	2	10
			Dense forest	2	10
			Settlement	3	15
			Moderate forest	3	15
			Agriculture	3	15
			Open forest	5	25
			Scrub	6	30
			wasteland	8	40
6.	Aspect	4	North	4	16
			North-East	5	20
			East	9	36
			South-East	8	32
			South	7	28
			South-West	6	24
			West	4	16
			North-West	5	20
7.	Distance to Road	3	Road Corridor (<=50 m)	4	12
			Rest of area	2	6

(Table 2 - Slope Stability Analysis weighting and rating system adopted in this study)

Computation

The classes of different data layers are assigned the corresponding rating value as attribute information in the GIS and an "attributed map" is generated for each data layer. The raster operation capability of ArcGIS 9.3 has been utilized for computation. A weighted Sum tool from an Overlay function in Spatial Analyst has been used to generate the output layer.

Weighted sum = ∑ [layer1 weightage + layer2 weightage+layer3 weightage……..layer n weightage]

One of the objectives of the present study is to prepare the LHZ map of the study area using Weighted Sum method. Therefore a Landslide Hazard Zonation map is prepared showing five zones namely very high hazard, high hazard, moderate hazard, low hazard and very low hazard using the reclassify operation.

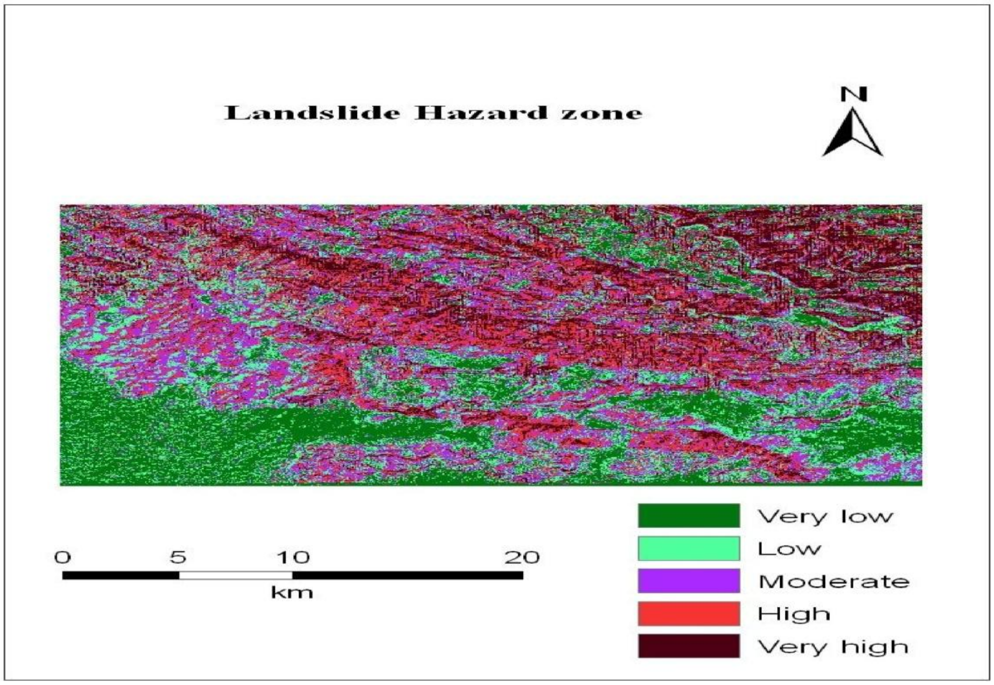

Fig. 3

Result & Conclusion

The weighted sum method is basically a qualitative method giving ample scope for incorporating expert knowledge in the hazard mapping process, which is essential to produce reliable LHZ maps. Though qualitative methods introduce some degree of subjectivity in the process, it cannot be considered as a reason for the inferiority of the method. Subjectivity implies mainly poor reproducibility of the output in repeated processes. In fact, the expert knowledge is essential to identify the contributing factors itself in the first place, whether it is for subjective analysis or for quantitative analysis.

The final Hazard zone map showing five classes of the hazard zone. These are namely very low, low, moderate, high, very high hazard zone. It has been identified with the help of the landslide inventory map that a large number of landslide events have occurred in the moderate and high landslide hazard zones and less number of landslides are identified in low and very low landslide hazard zone. Through the present study of slope instability analysis and LHZ mapping using Weighted Sum Method, it has been concluded that the Weighted Sum Method of Qualitative Approach in LHZ mapping is a reliable method. It seems to be very useful for quick and much accurate analysis of LHZ. The weight assigning to the parameters and classes is totally depends on the expert's decision, therefore it is necessary to have deeper knowledge of evidential parameters and their contribution in controlling the slope stability.

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