GIS based Landslide Susceptibility Analysis of extremely sensitive Dharamshala region, Himachal Pradesh, India

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Abstract
Landslide Hazards Zonation is one of the key tools for geologists, civil engineers, land-use planners and geographers for prevention and mitigation strategies for landslide. Primary step of present study is to prepare input raster layers of various factors that control landslides. Slope, geological formations, rainfall, land use, lineament density, drainage density and road density are seven controlling factors that are selected for this purpose. The weighted Overlay Method is extensively applied in the present study for assigning weights and ranks to various factors using Analytic Hierarchy Process. Using multi-criteria analysis which is based on ranks and weight, Landslide Susceptibility Index is calculated. Finally, Landslide susceptibility map of study area is developed.

Based on the susceptibility Index, study area is divided into five susceptibility zones from very high to very low. The classification is as very high (5%), high (26%), moderate (40%), low (28%) and very low zones (1%). This susceptibility zonation map is very helpful for an exhaustive study of the area concerning landslide prevention and its mitigation on one hand, as well as, proper land-use planning for tourism and societal development of Dharamshala city and its surrounding areas on the other hand.

Keywords: Landslide Hazards Zonation, Weighted Overlay Method, Analytic Hierarchy Process, Multi-criteria Analysis, Susceptibility Index.

Introduction

Landslides are considered as one of the most common and prominent natural hazard threatening lives, livelihoods, communities and resources in the hilly terrains[6,17,27]. The Himalayan terrain is very susceptible to slope failure and associated mass movements due to complex and adverse geological, tectonical and geomorphic setup[25]. Rainfall, earthquakes, unscientific practices, ongoing anthropogenic pressure of developments are also exacerbating slope failure in the terrain. Developmental activities are essential for ease and connectivity of hilly areas to major cities but scientific approaches and quality of constructions should be taken care. So the slope susceptibility is very essential to maintain the equilibrium in the Himalayan terrain. The areas susceptible to slope failure can be recognized using susceptibility analysis so that the impact of vulnerability on hazard and risk can be reduced[9,28].

Landslide susceptibility is significant for the identification and prediction of accomplishable landsliding zones[27,29] as well as for the development planning and risk management of vulnerable areas[11]. Geospatial techniques are used to extract the spatial and temporal data. Various controlling factors identified in the study area are: geology, structures (faults, thrust and major other discontinuity), lineament density, rainfall analysis, slope angle, slope direction, land use/landcover (LULC), drainage density and road density. These factors which are influencing the landslide probability are called induced and preparatory factors[1,2,16,21].

Landslide hazard zonation map was introduced for the Eastern Himalayas. Various thematic maps were integrated using simple overlay method in qualitative way on 1:50000 scale[7,8]. Various scientists used integration of multiple thematic layers to prepare the first LHZ map along National Highway[24,25]. Sengupta[24] emphasized "the importance of different causal factors of land sliding, for the preparation of a slope stability zonation map by manually overlaying of different thematic maps". In 2006, several landslide hazard zonation maps were prepared by Sarkar[23] along the Road Corridor of Sikkim Himalayas using a semi-quantitative heuristic approach.

The principal objective of present study is to calculate and to understand the relationship between various controlling factors and parameters that exacerbate landslides in the terrain. GIS and remote sensing techniques are used to develop information about preliminary factors like slope angle, lithology and geological structures (tectonic structure, faults mainly), land-use pattern, drainage information and road alignment which stimulate and initiate the landslides in Dharamshala and its surrounding regions.

Study area

The study area falls within $32^0$10'N to $32^0$14'N and $76^0$16'E to $76^0$24'E and forms an integral part of the outer Himalayas. The 1:50000 toposheet no. 52D/8 prepared by Survey of India covers the study area of 105 Km^2 around Dharamshala town. The major villages include Mcleodganj, Bhagsu Naag, Chola, Khaniyara, Kharota, Lungta etc. The major streams dissecting the study area are the Gaj, Churan, Manjhi, Manauni and Ikku Rivers. This specific area was selected due to the presence of various factors that control landslide

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activities in the area i.e. complex geology, active tectonics (MBT, MCT and other thrusts), rugged topography, adverse climatic conditions and anthropogenic activities.

Seismically, the Dharamshala region is most active and falls in zone V of the Indian seismic zoning map[5]. On 4th April 1905, this area witnessed one of the major earthquakes of Indian history the Ms 8.1 Kangra earthquake; approximately 20,000 people lost their lives and faced huge loss of property. Dharamshala is credited as being the third wettest place in the World, after Mawsynram and Cherrapunjee. Khaniyara is the wettest place in the Dharamshala region. It experiences mean annual rainfall of approximately 300 cm.

Tectonic and geological setting of study area: The lithology of study area is ranging in age from Precambrian to Quaternary divided by 3 major fault zones: the Chail Thrust considered as an equivalent to MCT i.e. Main Central Thrust, MBT i.e. Main Boundary Thrust and Drini Thrust. Besides these three major thrusts, there are several minor faults and lineaments noticed in study area (Fig.2).

The Northern limit of study area is marked by the rocks of Chail Group comprising gneisses, schists, greenish grey phyllites, slates and schistose quartzites of the Precambrian age. Phyllites are common in Dharamkot and Bhagsu Naag area, while towards Manauni Khad, Quartz-mica schists are abundant. The quartz-mica schist shows well developed schistosity and is abundant along Manjhi and Manauni khad in study areas. The shales are succeeded by Dharamshala traps at the eastern end of the study area and Dharamkot limestone and dolomites at its western end while a small patch of purple shales of the Subathu formation encounter in the middle of these two formations. The best exposure of the Subathu formation is noticed along Manjhi Khad in the Khaniyara area where it is in direct contact with rocks of Chail formation.

Further towards the south, this sequence is succeeded by rocks of the Dharamshala group of Miocene age composed of grey sandstone with clay and shales, siltstones and caliche. Dharamshala's are succeeded by a thick succession of Shiwalik sediments comprised of clay, sandstone and conglomerate. Shiwalik's are succeeded by quaternary alluvium, covering southern parts of the study area.

The rock sequence has been thrust and accreted to a great extent. The study area is crossed by the MCT which is a ductile shear zone, separating the crystalline rocks of the Higher Himalayas from the Lesser Himalayas. Its equivalent, Chail Thrust, separates Chail formation from the underlying Dharamkot formation, while in the Khaniyara region, the sharp contact is marked by Subathus and low metamorphosed Chails. The second major thrust, the MBT separates the Lesser Himalayas from Sub – Himalayas. In the study area, MBT separates Dharamsala Formation and Subathu Formation. Drini Thrust, a secondary thrust of MBT, separates upper Shiwaliks from the Dharamshala formation. The sharp contact between these two formations is noticed near Ghera village and the lower Sakoh area of the Dharamshala region (Fig. 2).

The area is wedged between the two collision boundaries i.e. MBT and MCT and linked with extensive continental convergence of the Indian plate moving in northward direction[26]. The presence of such major fault zones makes the area seismically active as well as susceptible to other geo-hazards like landslides.

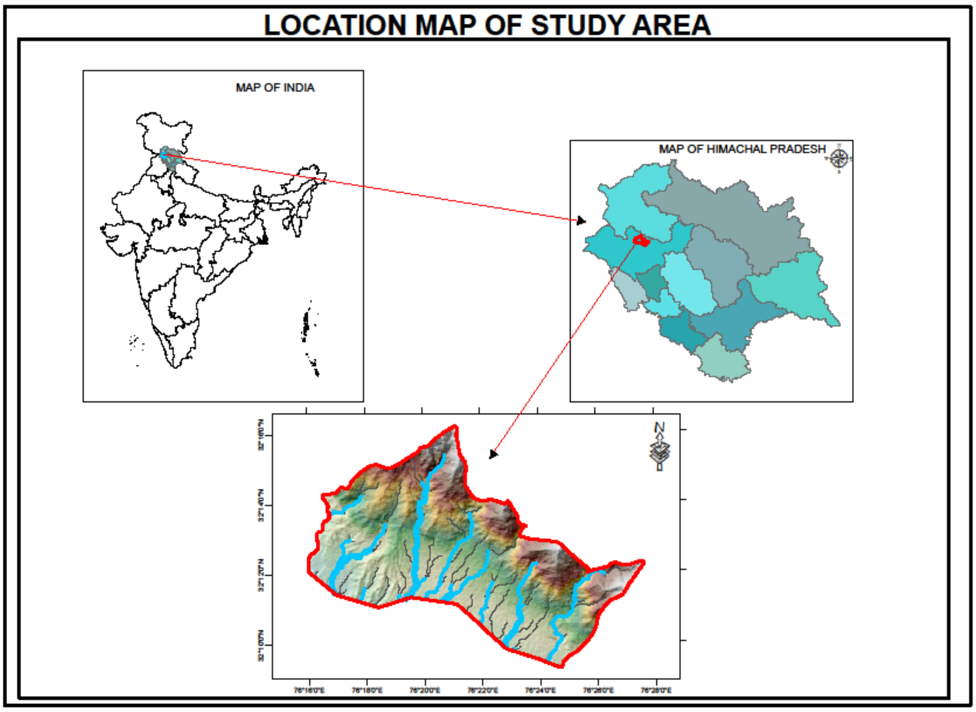

Fig. 1: Location Map of Study area

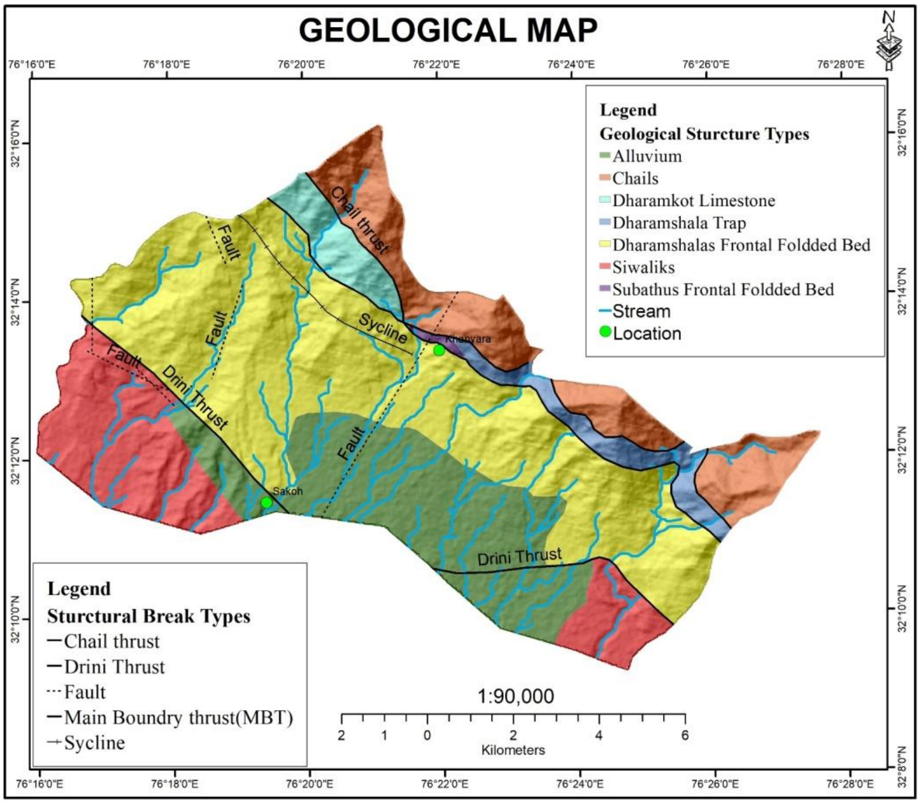

Fig. 2: Geological Map of study area

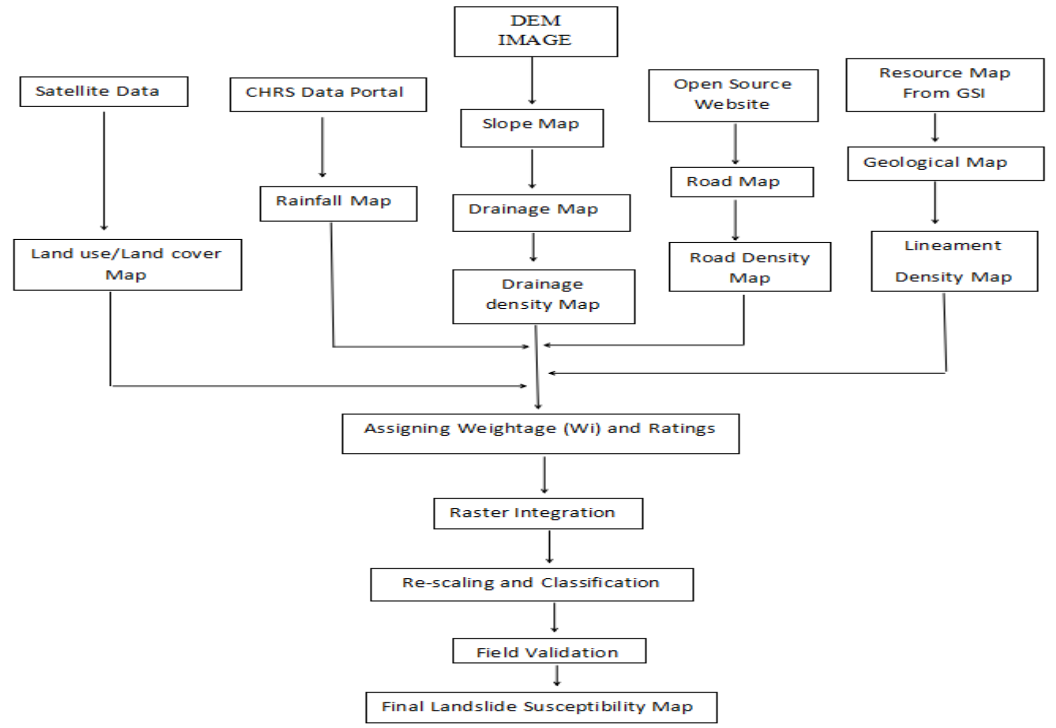

Fig. 3: Flow chart of Methodology

Material and Methods

The geological map of the study area was prepared based on the previously published map[14]. Susceptibility mapping for present study has been carried out using Weighted Overlay Method. The complete methodology is displayed in figure 3. Raster data such as slope, geological formations, landslide types, LULC, lineament density, drainage density and road density have been derived from the 1 sec SRTM DEM and ASTER-II DEM (~30 m resolution). Land-use map is prepared using Satellite Imagery Landsat 8 ETM+. Datum (WGS84) and UTM projection have been maintained for processing several datasets.

All these 7 raster layers are assigned weightages (Wi) depending upon their influence to trigger the landslides; in the present study. Weightages were assigned as percentage, based on the Influence of each category on initiation of land sliding (Table 1). Each attribute is sub-categorised into different classes and given ranking again in percentage. The cell value of each input raster is multiplied by the raster's percentage influence. The resulting cell values are added to produce the final output and analysed using the weighted overlay method (WOM) in ArcGIS 10.5 desktop.

The mapping, calculations and analysis are the same for each parameter. These layers/attributes are overlaid to form a single composite layer. Using this composite layer, a landslide susceptibility map of the study area is prepared with five classes viz. very low to very high. Finally, the landslide susceptibility map is validated with field investigation and actual landslide initiation data along with the study area. An overview of the methodology is shown in the flow chart (Fig. 3).

Results and Discussion

Slope: Slope gradient is one of the most important parameters in slope stability analysis[12] and is frequently used in landslide susceptibility analysis as well as in LHZ mapping[13,22]. The slope map of the study area is prepared with the help of DEM using GIS tools. The map is classified into five categories ranging from very high to very low (Fig. 4 A). Very high slopes ranging from $40^0 – 60^0$ and above were found to be more susceptible to land sliding and hence given a rating of 40, others have given rating 25,15,5 and 5 respectively (Table 1).

Table 1
Weights and ranking are assigned to various factors controlling land sliding in the study area.

Factors	Weights (%)	Class	Rating
Slope	40%	40^0-60^0 and above 30^0-40^0 20^0-30^0 10^0-20^0 0^0-10^0	50 25 15 5 5
Lithology	15%	Dharamshala Formation Subathu/Chail Formation Dharam kot limestone Shivalik formation Dharamshala traps/ alluvium	50 20 15 10 5
Rainfall	10%	1,260-1,280 1,240-1.260 1,220-1,240 1,200-1,220 1,180-1,200	50 20 15 10 10
Land use / Landcover	10%	open forest Erosional Area Agriculture Snow Forest Built-up	40 20 20 10 5 5
Lineament density	10%	Very high High Moderate Low Very low	50 20 15 10 5
Drainage density	10%	Very high High Moderate Low Very low	50 20 15 10 5
Road density	5%	Very high High Moderate Low Very low	50 20 15 10 5

Lithology: The lithology is one of the prime factors that control slope and significantly affect landslides, especially in hilly regions[16]. Different lithology's have different susceptibilities toward various geomorphological processes and hence, play a significant function in LHZ studies[19]. The major lithology of the study area includes slate, phyllite (Chail formation), sandstone, silt, clay (Dharamshala formation), purple shale (Subathus), limestone, dolomite (Dharamkot formation), Dharamshala trap, conglomerate (Shivaliks) and Quaternary gravel (Fig. 2). Weightage and rating to various formations are shown in table 1.

Rainfall: Precipitation is a major triggering factor for slope failure. The study area is recognized as the third wettest place in the world. An annual average rainfall map for the period from 2010 to 2020 has been prepared as shown in figure 4B. This map indicates that the intensity of rainfall increasing with altitude. Consequently, the risk and impact of slope failures are greater in areas with higher rainfall intensity.

There is a direct correlation between the intensity of rainfall and the likelihood of slope failure. The higher is the rainfall intensity, the greater are the chances of slope failure. Any variation in rainfall intensity can alter the frequency and occurrence of landslides.

Landuse / Landcover: LULC is also an important factor that control slope stability/instability[3,18]. Changes in land use patterns are considered as a significant parameter in assessing landslide hazard. The thick vegetative cover has a large potential to reduce the rate of landslide by increasing the soil binding through root reinforcement[4]. Changes in the land features in the past can directly be recorded using satellite imagery. For the present study, the land use data is obtained from high-resolution satellite images. After analysis of this remotely sensed data, the study area is divided into seven land-use classes namely, Agriculture, Built up, Erosional Area, Forest, Open Forest, River, Road and Snow.

The land use/ Landcover raster layer is re-classified into 6 classes assigned a weightage of 10%. All six classes have been given ratings and the highest rating 40 is given to open forests and the lowest to forests and built-up land. The rating is assigned to different subclasses according to their influence on triggering landslides (Table 1). The spatial distribution of the LULC map as per the rating score is shown in fig. 4C.

Lineament density: The structural breaks like thrusts, faults and shear zones are considered one of the important parameter for landslides[20] due to weakening of rocks[10,22]. These structural discontinuities are exacerbating landslides significantly in the study area. The study area witnessed many major landslides around such planes MCT as well as along MBT in the Khaniyara area and along Drini thrust in Ghera and Sakoh. The lineament raster layer is reclassified into 5 sub-classes viz. very high, high, moderate, low and very low. The spatial distribution map of Lineament Density is shown in fig. 4D.

Drainage density: Drainage density may be defined as the measure of the total length of a stream per unit area of the drainage basin. Erosional activities are directly proportional to drainage density i.e. the higher is the drainage density, the lower is the infiltration and hence, the higher is the surface flow[15], ultimately higher is the rate of erosion, which exacerbate slope failure in the area[3].

The weightage (Wi) of 10% is assigned to drainage density (Table 1). The drainage density layer is further sub-divided into 5 sub-classes i.e. very high, high, moderate, low and very low assigned ratings of 50,20,15,10 and 5 respectively (table 1). The spatial distribution of drainage density is shown in fig. 4E.

Road density: Road density may be defined as the measure of the total length of road network per unit area. It is also an important parameter to induce landslides. The majority of landslides in the study area can be noticed along the roadside. The weightage (Wi) of 5% is assigned to road density. The drainage density layer has 5 sub-variables from very high to very low assigned ratings from 50 to 05 as shown in table 1. The spatial distribution map of drainage density is shown in fig. 4F.

Peak ground acceleration (PGA) value: PGA is a parameter to represent the peak ground acceleration due to earthquake vibrations and hence, it is an important factor for slope failure. The study area is an integral part of NW-Himalayas and belongs to seismic zone 5. Due to lack of the more detailed data on PGA distribution, this value is considered to be approximately the same (0.36 m/s^2) throughout the study area, and, thus, has a similar impact on slope stability. Numerous earthquake-induced landslides have been reported to occur here. A landslide in 1986 in the Dharamshala region was caused by an earthquake that occurred on 26th April and it was one of the major earthquake induced landslides in the area. Each attribute layer is prepared in the GIS domain. The final output is produced by multiplying the cell value of each raster layer by the raster's percentage influence.

Final spatial layers are then overlapped using a weighted overlay tool, to give a composite image that provides index values to classify the susceptibility zones into five classes viz. very low (0-1), low (1-2), moderate (2-3), high (3-4) and very high zone (4-5). For field validation, the landslide point locations are overlaid on susceptibility classes and it was observed that the landslide frequency (%) gradually rises from very low to very high susceptibility zone. The very high landslide zone occupies an area of about 2.25% of the total area, the high susceptibility zone occupies 29.84% of the total area, medium susceptibilities zone occupies 43.32%, the low susceptibility zone occupies 24.36% while the very low susceptibilities zone occupies an area of 0.33% of the total study area.

Landslide susceptibility analysis: A landslide susceptibility map identifies the areas prone to landslides, measured from low to high. The study area has been divided into several terrains for the evaluation of various causative factors for slope instability.

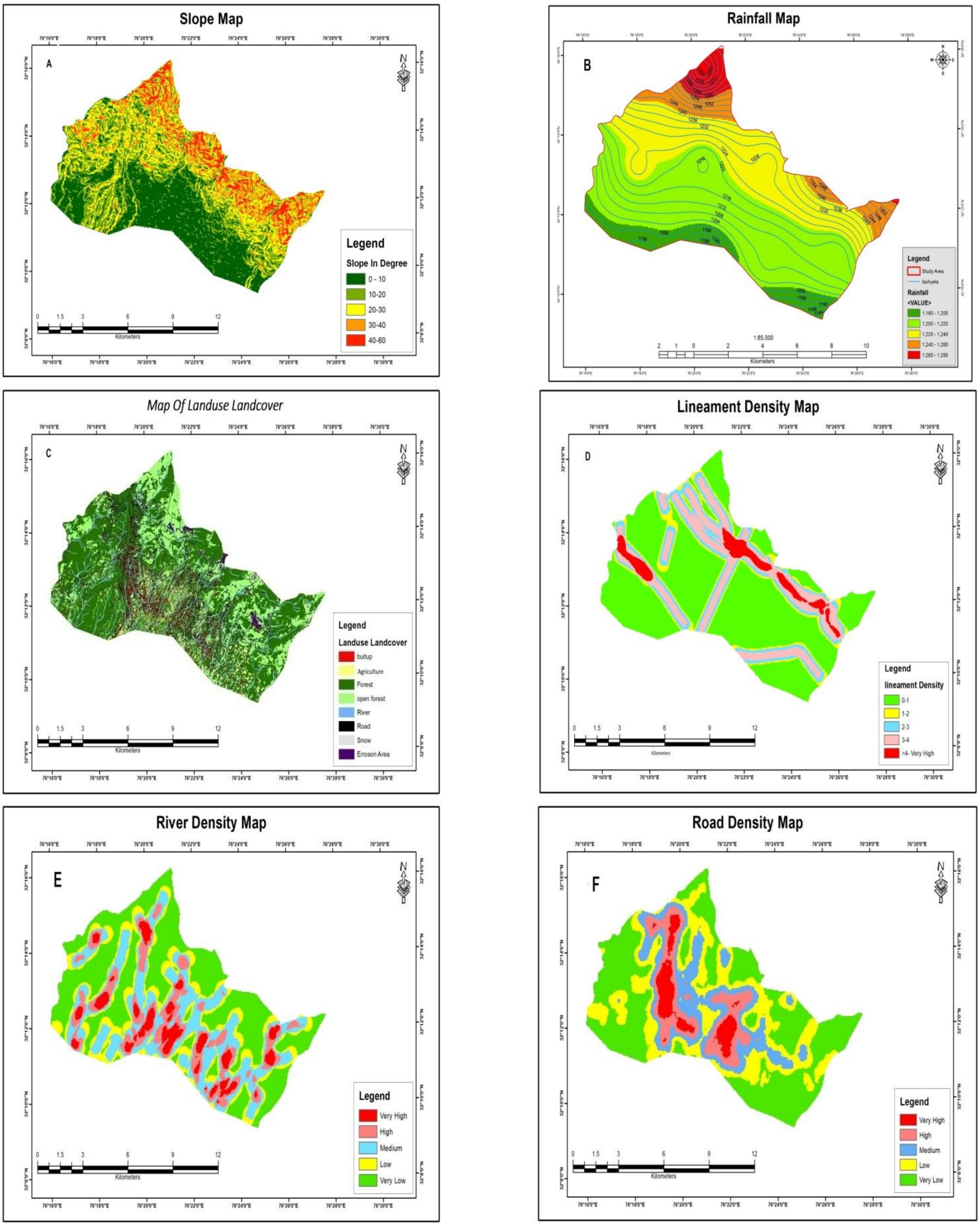

Fig. 4: Landslide contributing factors (A) Slope, (B) Rainfall, (C) Landuse/Landcover, (D) Lineament, (E) River Density and (F) Road density

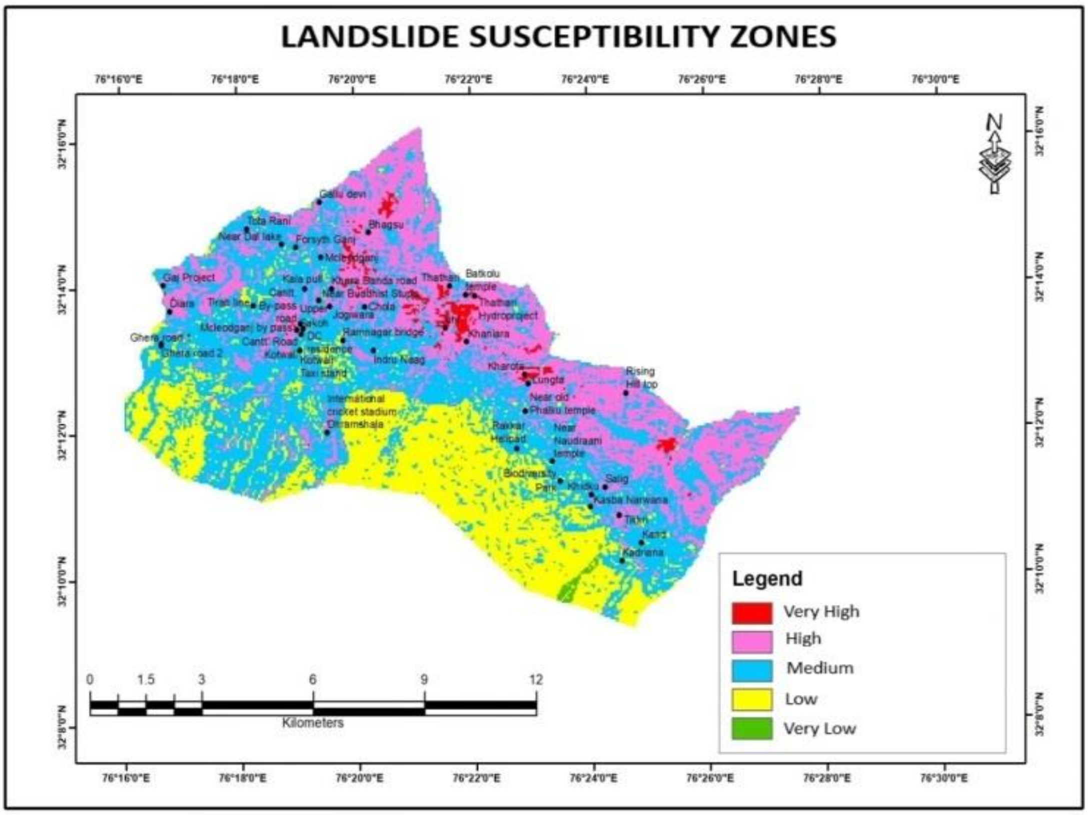

Fig. 5: Landslide Susceptibility Zonation Map of Study area

Different attributes are studied and analysed carefully and a numerical rating scheme is developed to assess the susceptibility index. Landslide susceptibility analysis in the present study has been done using the weighted overlay method.

Conclusion

Based on the weightage to various triggering factors, a spatial distribution map of Landslide susceptibility zones has been prepared (Fig. 5). From this landslide susceptibility zonation map, it is inferred that approximately 34 km^2 area is under very high to high susceptibility zone which is about 32% of the total study area. This is the region where there is a possibility of sliding of debris and other loose earth materials along a steep slope (above 40^0) and occupies the maximum of the Northern part of the study area. Both of these zones are surrounded by steep slopes and tectonic breaks like Chail thrust, MBT and Drini thrust and also the area lies on weak lithology of Dharamshala formation.

Mitigation measures should be taken to control land sliding activities in this region with detail investigation i.e. detail geological, geotechnical and geophysical analysis. Present zonation map can be used by land use planners and may also become a useful tool for the preparation of mitigation strategies at various levels.

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