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Development of Methodology for Identification of Landslide Susceptible areas along NH-10 from Singtam to Gangtok, East Sikkim using GIS based Modelling

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

Department of Applied Geology, Dr. Harisingh Gour Vishwavidyalaya, Sagar 470-003, India
Email: *vjsagar.geo[at]gmail.com*

Abstract: ***Around the world, landslides are a common phenomenon or natural disaster. The NH-10 has been chosen for identification and examinations of slope failure processes in order to better understand the impact of landslides and mass movements in the Sikkim region. The NH-10 is the only communication system in this region and called as a life line of the state that also fulfills the demands of defense forces working in border areas. The 18 km stretch of NH-10 between Singtam and Gangtok has been chosen for the current research. This road length is affected by various types of mass movements. Geology, hydrology, seismicity, engineering behaviour of slope forming material, etc. are the main reasons of this mass movement. Besides these, the study area is also affected by heavy rainstorms and alteration of geometry of slope which consequently results different types of slope failure phenomenon. Geologically, the area is made up of mainly quartzite and phyllite which belongs to Goruba than and Reyong Formations of the Daling Group. Further, an attempt has also been made to mark the landslide prone areas along the road with help of different types of thematic maps. The study involved preparation of various thematic maps for geo-factors. A weighted multiclass index overlay method was used to categorise the landslide susceptible slopes. The input thematic maps integrated through a knowledge-driven integration technique. The Author (s) have prepared the Digital Elevation Map, Slope map, Aspect map, Drainage map, lineament map and landslide susceptible map using ALOS PALSAR DEM on Arc GIS 10.5 software.***

Keywords: Landslides, Thematic Maps, NH10, Sikkim etc.

1. Introduction

Landslides or slope instability due to various natural factors, like heavy rain, avalanche and earthquake etc., is a major issue for Himalayan terrain. The Sikkim state gets affected by slope instability problems every year causing damage to properties and life. The entire road network in Sikkim is affected by the various types of mass movements, which are the result of combined action of geology, hydrology, seismicity and engineering behaviour of slope material. Further, in order to understand this phenomena, Remote Sensing and GIS techniques have been utilized and different types of Thematic maps like Slope map, Slope Aspect map, Drainage Map and Contour map of the study area have been prepared to identify landslides prone areas on the ALOS PALSAR DEM data with the help of ARC GIS software.

2. Study area

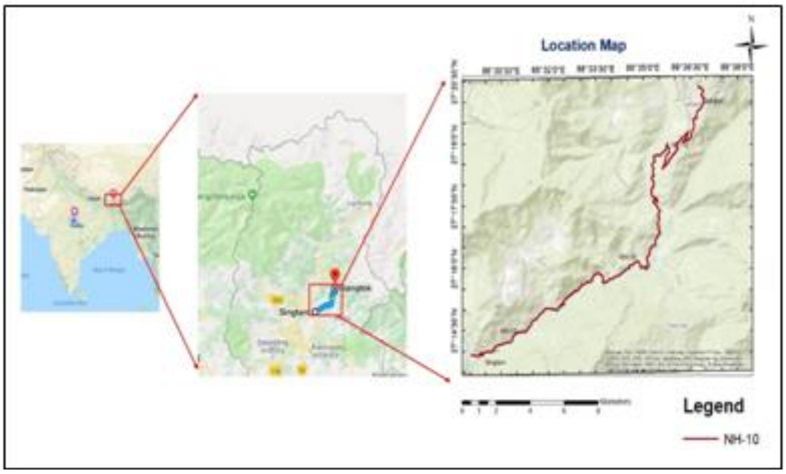

Figure 1: Location Map of the study area

The study area falls under the survey of India toposheet number 78A/11, 78A/8 and 78A/12 and between the latitude27°14´N to 27°21´N and longitude 88°30´E to 88°40´E. National Highway 10 in North eastern India that connect Indo-Bangladesh border via Siliguri to Gangtok. A road stretch of about 18 km from Singtam to Gangtok along NH-10 has been selected, which falls in lesser Himalaya portion of the Sikkim region, which occupies the Daling group of rocks. Study area have ridge and valley topography due to which landslide more frequent here.

Data and Software Used:

For landslide susceptibility analysis required spatial data were collected from different places and website. Topographic Basemap, Google earthand ALOS PALSAR DEM (12.5 m resolution) data have been used for generation different thematic maps of the study area. Arc-GIS 10.5 and Erdas Imagine 2014 used for preparation and analysis of different maps.Geological map and Geomorphological required for landslide susceptibility analysis and it collect from Geological Survey of India. The DEM data used to extract slope angle map, slope aspect, drainage and drainage density map. Rainfall data were collected from India meteorological department.

The Geology of the Study area:

The State is mostly covered by Precambrian metamorphites of low to medium grade (Daling Group), high grade gneisses (Darjeeling Gneiss and Kanchendzonga Gneiss), Chungthang Formation (quartzite, calc-silicate rocks, marbles, graphite schist's and occasionally amphibolites) with intrusive granites (Lingtse granite gneiss).The Paleozoic and Mesozoic (Tethyan) sequence in the northern and north-western part of Sikkim are fossileferous. The Gondwana super Group consists of sandstone, shale and carbonaceous shale with occasional thin bands of coal and pebbly shale horizon.

Geology of Study area (Fig. 2) include Daling group of rocks consisting Gorubathan Formation characterized by quartz-chlorite-sericite schists, phyllite and quartzites and Reyang Formation characterized by quartzite, phyllite inter banded with carbonaceous slate (Rawat, M.S, 2012).

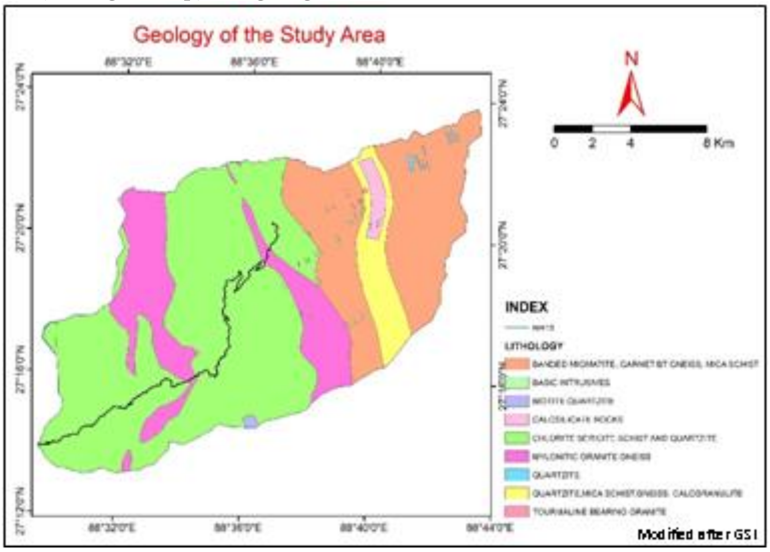

Figure 2: Geological Map of the study area

Digital Elevation Model:

A digital elevation model (DEM) depicts the spatial extent of topography of the region and can be used to derive relative relief, slope, and slope direction (i.e., aspect), which are influential in causing landslides in a given region (Fig. 3).

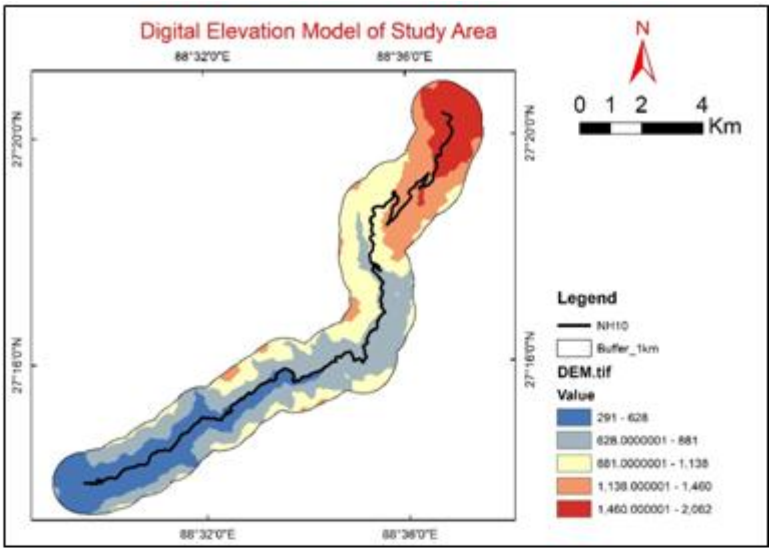

Figure 3: Digital Elevation Model of the study area

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Slope Map:

Slope plays a significant role in landslide phenomena. Slope map presenting the value of inclination. Steep slope represented here in this map with red colour having slope angle 55°- 83° is very prone to landslide and very gentle slope to flat represented by Dark green as shown in map having slope angle 0° to 12° is very less (Fig. 4).

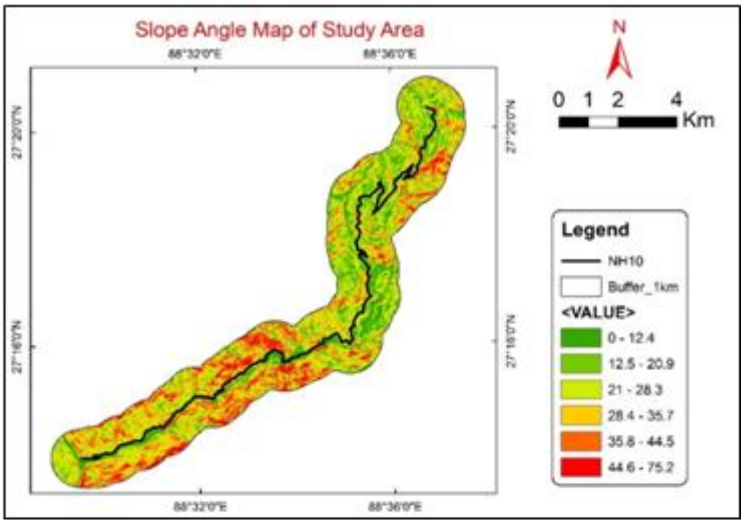

Figure 4: Slope map of the study area

Slope Aspect Map:

Slope aspect map is one of the important parameter to identification and preparation of landslide susceptible zone maps. The slope which is more expose to solar radiation and rainfall, action of weathering and erosion will be high on that and they will be prone to mass movement compare to other. The aspect map of the Singtam to Gangtok area was derived from ALOS PALSAR DEM. The slope aspects of entire basin is divided into ten categories, those are flat—1, north 0–22.50, north-east 22.5–67.50, east 67.5–112.50, south-east 112.5–157.50, south 157.5–202.50, south-west 202.5–247.50, west 247.5–292.50, north-west 292.5–337.50 and north 337.5–360.Aspect map of the study area indicates that slope facing direction variable along the river, the south to south-east-facing slope are dominant along the right bank of the main stream and high percentage of north to north-west-facing slopes are dominant along its left bank (Fig. 5).

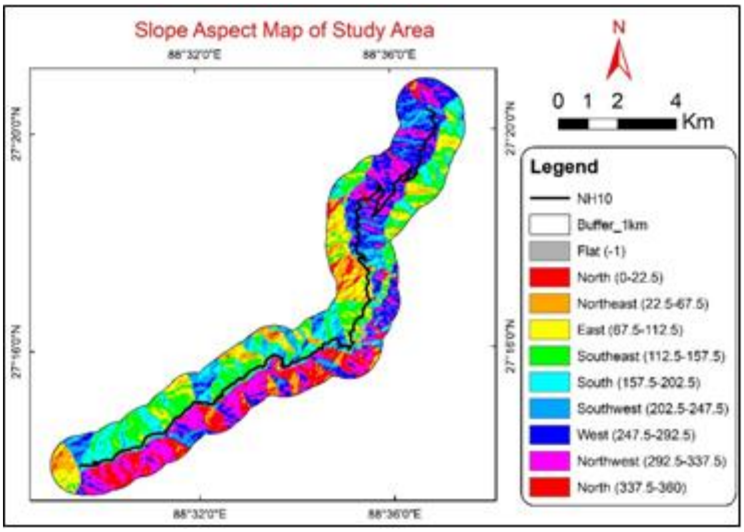

Figure 5: Slope Aspect map of the study area

Geomorphological Map:

The shape of the geomorphic units in the study area is mostly controlled by the geological structures and degree of dissection (Agrwal and Kumar, 1973).The map was prepared by downloading and processing the data from Bhukosh in Arc-GIS. It shows various morphological features present in the study area. Geomorphologically the study area is divided into 05 classes i.e. Highly dissected Hills and Valleys, Moderately dissected Hills and Valleys, Terrace, Valley, and water bodies (Fig. 6).

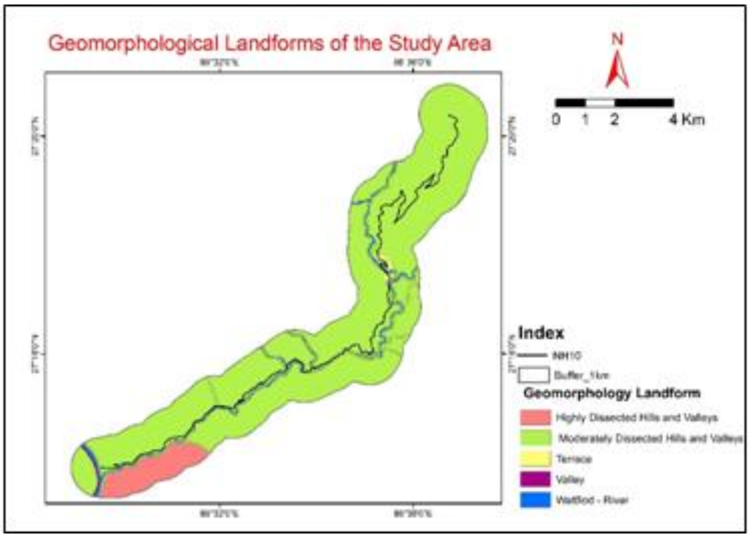

Figure 6: Geomorphological Landforms of the study area

Drainage Map:

Drainage in the area is very important geo-factor to be identified and used as predictor for landslide incidences. With the help of drainage map we identify the slope and area those are highly prone to mass movement. The surface runoff may causes extremely rapid soil erosion of the slope material causing slope failure, resulting in heavy loss of lives and property (Rawat, R. K., Trivedi, R. K., & Soni, L., 2007). Drainage is occupied by the Rani-khola or Rongni-chu at foothill region flowing mainly towards South-East. Drainage pattern is draindritic. Drainage basin of the Study area contains maximum 5th order of stream which is determined by the Strahler method of stream ordering. NH-10 is nearly parallel to the highest order of stream in the lower part of the basin dominate the high toe erosion which is one of the significant cause of slope failure (Fig. 7).

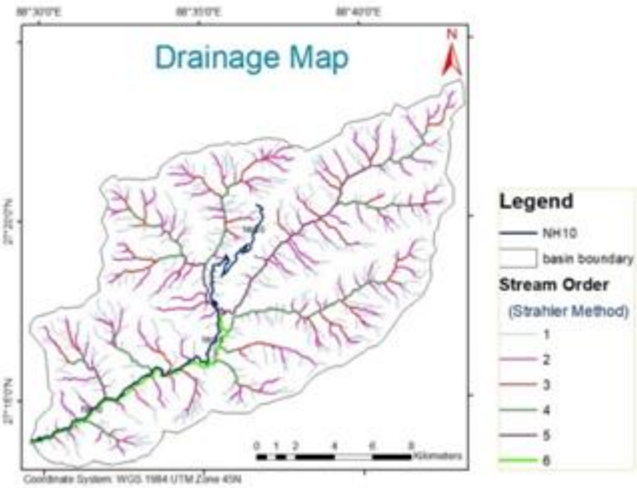

Figure 7: Drainage Map of the study area

Drainage Density Map:

The drainage of the area generated with the help of Satellite imagery and Survey of India toposheets *i.e.*, 78 A/8, 78A/11 and 78A/12. The Drainage density calculated from the formula that is the total line length of the stream network divided by basin area. High density (red colour) indicate a mature or well developed channel system, Over landed flow to channels, thin/ deforested vegetation cover, basin rocks/soil has generally less infiltration rate and also represent the texture of a stream network. The low drainage density (Grey colour) is favoured in regions of high infiltration rate and dense vegetative cover (Fig. 8).

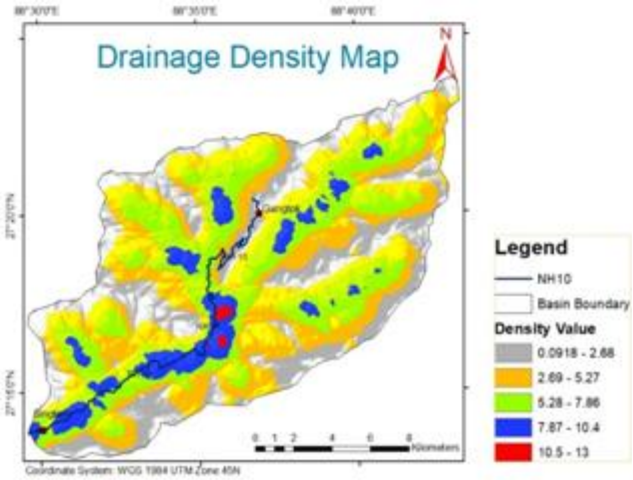

Figure 8: Drainage Density Map of the study area

Lineament Map:

Lineaments, including linear geological structures, contribute significantly to mass movement processes in hilly terrain (Kanungo et al., 2006). Lineaments were mapped from the satellite image in erdas imagine software by visual interpretation aided by field verification. Structural features Lineaments include all structural, topographical, vegetational and lithological alignments, which are likely to be the surface expression of buried features and structures. Generally, these are related to fracture systems, discontinuity planes, faults, and shear zones in the rocks, and proximity to such features facilitates landslides. Lineaments describe the zone/plane of weakness, shearing, and tectonic activity along which the landslide susceptibility is higher (O'Leary et al. 1976). In this study, lineaments have been interpreted from the ALOS PALSAR and Toposheet. Major trend of lineament is NE-SW and NW- SE (Fig. 9).

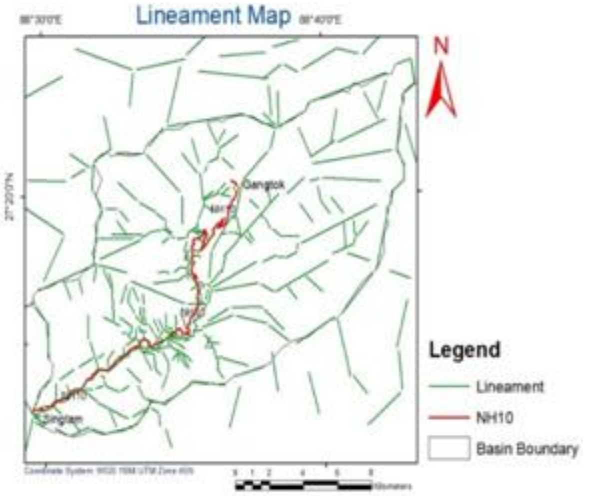

Figure 9: Lineament Map of the study area

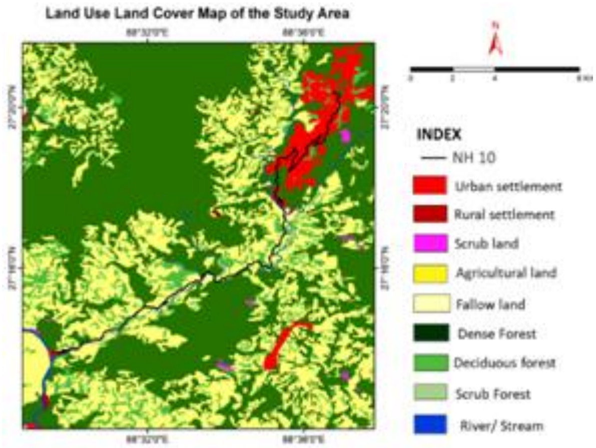

Figure 10: Land Use Land Cover map of the study area

Land use Land cover map:

Land Use Land Cover map assessment is an integral part of scientific analysis and it provides information about the landscape of a particular area. LULC map of study area has been prepared by using thematic dataset. The source of the data is Resourcesat-2 ortho rectified LISS-III data of 2015-16 and entire database are prepared by NRSC, ISRO under Natural Resources Census (NRC) Project of National Natural Resources Repository (NRR) Programme. With the integration of this geospatial dataset onto arc GIS web server, LULC map (1:50, 000) of study area has been prepared. On the basis of the above mentioned sources total Nine nos. of classes has been identified in study area such as Urban settlements, Rural settlements, Scrub land, Agriculture land, Fallow land, Dense forest, Deciduous forest, Scrub forest, and River/Stream (Fig. 10).

Rainfall and Climate:

Average annual rainfall is about 300 to 400 mm with maximum rainfall during the months of May to September in the study area. Few winter showers are also very common. Varied climate conditions of Sikkim are mainly due to variation in altitude. The climate varies from the tropical heat of low valley bottoms to the alpine cold of higher reaches. The moist tropical climate is experienced up to an average altitude of 600 m. Beyond that, a subtropical climate prevails up to an elevation of about 1500 m. Thereafter, the cold temperature climate conditions are found up to an altitude of around 3000 m. Further up, it becomes progressively cooler. During the summer, the maximum temperature goes up to 25°C being slightly higher in the valley areas, whereas during winter the temperature drops down to 1°C or below. Graph showing 2009 to 2018 rainfall of monsoon season in east Sikkim. The frequencies of incidence of landslides are very high during monsoon season because of heavy rainfall (Fig. 11).

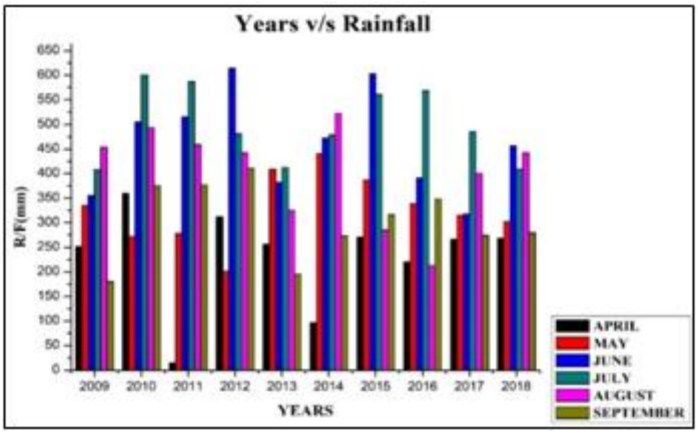

Figure 11: Histogram of rainfall v/s years of the study area

Landslide Susceptible Mapping:

The Landslide Susceptible mapping of the road corridor NH-10 from Singtam to Gangtok was carried out on a mesoscale (1:10, 000) in parts of toposheet numbers 78A/11, 78A/8, 78A/12. After the preparation of, the landslide susceptibility map was divided into three suitable classes (Low, Moderate, High) using manual classification method in Arc Map software to demarcate different landslide susceptibility zones (LSZ). From the map it is very evident that, the north-western stretch of the basin is more susceptible to landslide.

This map depicts that the area near the Martam & Sangkhola landslide fall in the high susceptibility zone (Fig. 12).

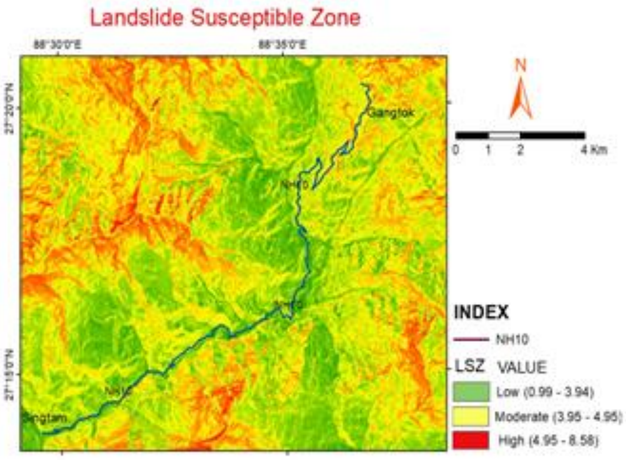

Figure 12: Landslide Susceptible Map of the study area

Landslides along NH-10:
The area is well connected through the network of roads like Siliguri-Gangtok national Highway (NH-10), and others State Highway (SH) connecting to the districts & villages of Sikkim State. Construction and widening of roads has been responsible over the years for making slope unstable and subsequent development of several landslides due to loosening and toe erosion. Moreover, bank erosion adds to the problem on roads developed alongside of the rivers/streams, due to continuous toe erosion by torrential stream conditions. Besides, the debris flow along the nala/topographic depressions towards road and river as slope wash and blocks the roads at any places during rainy season. Martam slide, Sangkhola slide, 9th mile slide, 32nd mile Slide on NH-31A along the river are some of critical slides in the area. In these landslides several mitigation activities (construction retaining wall, gabion wall etc.) done in regular interval of time by the concern departments of State Government and BRO to clear the road but still these landslides have not been arrested completely.

Integration of thematic layers and their analysis:
In GIS-based data-driven methods such as Weighted Multiclass Index Overlay, spatialfactors (or layers of evidence) are integrated. The causative factors are surface and bedrock lithology and structure, bedding altitude, slope steepness and morphology, climate, vegetation cover, land use and anthropogenic activity. The various thematic layers, such as, slope map, geological map, Geomorphological Map, LULC Map, lineament map, Drainage map etc. were arranged in hierarchical order of importance and a weighting number (from 0 to 9). Steep slope has high tendency to fall under the influence of gravity or other triggering factors. Lineament in this region are dominating in two directions NE-SW and NW- SE. Mass movement can take place along these weak plains. The mass movements decrease as distance increases from any lineament or thrust. The Histogram of Years v/s Rainfall shows high rainfall in monsoon seasons specially in the months of May to August, therefore the phenomena of landslide more frequent during monsoon or after monsoon. As a result, the process for landslide susceptibility mapping can be broken down into the following key topics, which are represented in a flow diagram. (Fig. 13.)

i) the construction of a GIS-based database for landslides and the roles of geo-factors in landslides, ii) empirical selection or geographical association study between various geo-factors and landslides to establish the weights of the geo-factor themes as well as the ratings of factor classes, iii) GIS-based modelling to use chosen and weighted geo-factor maps to create landslide susceptibility scores, and iv) Validation and classification of qualitative maps displaying varied levels of landslide susceptibility from landslide susceptibility maps.

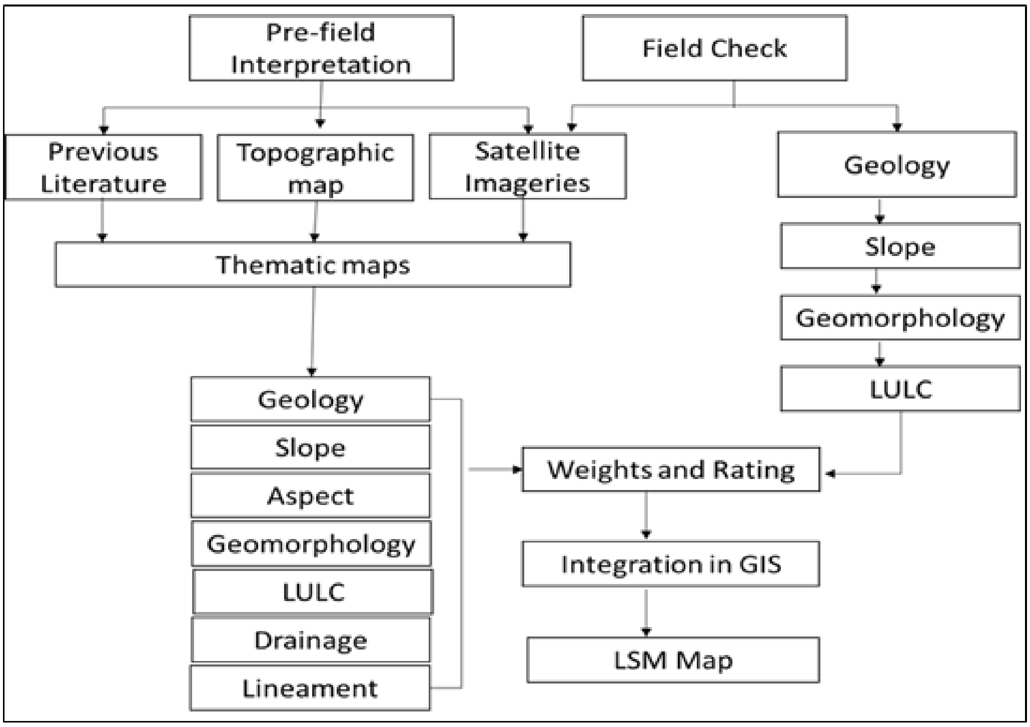

Figure 13: Flow diagram showing methodology used for landslide Susceptibility mapping

3. Conclusion

Landslide susceptibility is a quantitative or qualitative estimate of the spatial distribution of landslides, which exist or potentially may occur in an area. Landslide susceptibility analysis based on GIS widely used. GIS based methods are very suitable and it has higher acceptability for the unapproachable areas where data availability is less through field investigation. Prediction and forecasting of landslides are not easy task. In this regard, a landslide susceptibility map may provide brief and necessary information about slope instability of a particular region. Landslide susceptibility map can be a useful tool for the decision makers and planners as it demarcates and delineates the potential areas of future landslides. As landslide is a complex natural phenomenon, is driven by a number of factors those are not equally responsible for the event. After the thematic maps studies and field check it is observed that most of the slides are debris slide, rock slide are also common in some of the areas. If we classified the landslides in the study area most of the slide fall under shallow translational failure mechanism. Landslides are more likely to occur on slopes with mild to very steep angles between 25° and 45°, slopes facing SE, SSE, and SSW, and slopes with concave and severely concave facets. Due to heavy rainfall, rainwater that perculate inside the rocks through the fractures and cracks and work as lubricant is one of the most important cause for the incidences of landslides. The outcome of this study agree well with the previous studies in the Himalayas that slope angle angle between 25° to 55° has strong relationship with the mass movement (Sarkar and Kanungo, 2004; Saha et al., 2005; Kanungo et al., 2006).It is therefore all- important that remedial and preventive measures are planed to protect life and property from future landslides.

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