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LANDSLIDE HAZARD AND ITS MAPPING USING REMOTE SENSING AND GIS

Praveen Kumar Rai[1*], Kshitij Mohan[2] and V.K.Kumra[2]
[1]Assistant Professor (PGDRS & GIS)
[2]T.A. and [2]Professor, Department of Geography, Banaras Hindu University, Varanasi
*Corresponding Author, Email : rai.vns82@gmail.com

Abstract

Landslides are amongst the most damaging natural hazards in the mountainous terrain like Himalaya. The study of landslides has drawn worldwide attention mainly due to increasing awareness of socio-economic impacts of landslides. Remote sensing images provide many useful land use information to combine in a GIS environment with other spatial factors influencing the occurrence of landslide. The landslide inventory is a fundamental prerequisite for landslide hazard analysis based on GIS. The satellite imageries of LANDSAT ETM+, IRS P6, ASTER etc. along with Survey of India (SOI) topographical sheets form the basis for deriving baseline information on various parameters like slope, aspect, relative relief, drainage density, geology/lithology and land use/land cover.

Keyword: Landslide, Himalaya, GIS, Remote Sensing Image, Survey of India etc.

Introduction

When a rock has been disintegrated and decomposed by the process of weathering , weathered material soaked with rain water may slide down due to gravity. Such a sudden downward slip movement of rock debris is called landsliding. They can occur on any terrain given the right conditions of soil, moisture, and angle of slope. Integral to the natural process of the earth's surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow mud flows, debris flows, earth failures, slope failures, etc. Occurrence of landslides is particularly common in geodynamic sensitive belts i.e. zones and areas repeatedly rocked by earthquakes and affected by other neotectonic activities (Bolt *et. al.,* 1975). The Darjeeling Himalaya eg. recorded more than 20,000 landslides in one day is most vulnerable belt of Himalayan range. In 1968, it caused death of nearly 30,000 persons.

The principle factors that initiate or trigger mass movement are: (i) heavy and prolonged rainfall (ii) cutting and deep excavations on slope for construction of building, roads, canal and mining without appropriate disposal of debris, and (iii) earthquake shocks and tremors.

Since the factors affecting occurrence of landslides can be geophysical or man-made, they may occur in developed or undeveloped areas, or any area where the terrain was altered for construction of roads, houses, utilities, and even for lawns in one's backyard (USGS, Planning Research). The Himalaya is seismically the most active segment of the Indian sub-continent, its north-eastern and north western ends being repeatedly and violently rocked by earthquakes of considerable magnitudes. The amount of rainfall over wide areas is in excess of 200 cm/yr. in the outer ranges and the network of roads (> 4400 km. in aggregate length) constructed without considering the vulnerability of the region entail generation of colossal volumes of debris that increases the intensity of erosion.

Wide spread deforestation for development activities and increasing population pressure has forced people to move up the steeper forested slopes with their ploughs and livestock's (Saxena, 1981). It further aggravates occurrence of landslides in terrain of varying relief.

Factors governing stability of slopes and causing mass movements are :

(i) Angle of slope and attitude,
(ii) Lithology,
(iii) Structure,
(iv) Hydrological conditions, and
(v) Sensitivity in the area

Studies revealed that major forces operating on slopes are: (a) weight of the material building the slope i.e. rocks, soils, vegetation and man-made structures which act downward, and (b) the shear strength of the materials acting in the potential slip planes. Water is not only the main agent of rock weathering producing self coherionless and yielding materials but also the principle cause of mass movement. It reduces the shear strength of the rocks.

The principal driving force for any landslide is the gravitational force and the movement of this mass will be proportional to the hill slope angle. The resisting forces preventing the mass from sliding down along the slope are inversely proportional to the same hill slope angle and proportional to the friction angle of the material. In addition, the resisting forces can be significantly reduced in case of prolonged rains or earthquake vibrations. The speed at which different type of landslides occur varies greatly (Fig. 1). It is observed from the diagram that failure speed of rock fall is much higher than the one observed in slumps or soil creeping.

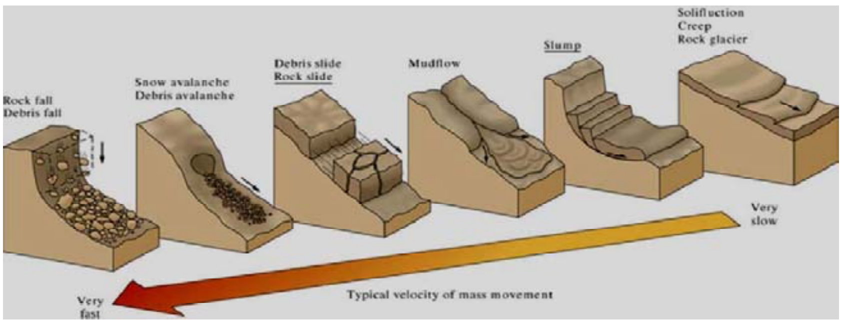

Fig.1 Relative failure speed for different types of landslides

Landslide Susceptibility Zonation (LSZ) relies on a rather complex knowledge of slope movements and their controlling parameters. The reliability of landslide susceptibility maps depends mostly on the amount and quality of available data, the working scale and the selection of the appropriate methodology of analysis and modelling. The process of creating these maps involves several qualitative or quantitative approaches (Soeters and Van Westen, 1996; Aleotti and Chowdhury, 1999; Guzzetti *et. al*., 1999, Onagh *et. al*., 2012).

Landslide Material

The type of landslide that occurs in a given location often depends on the composition and type of material which form the ground near the surface.

Table 1: Relationship between types of movement and the types of material.

TYPES OF MOVEMENT		TYPES OF MATERIAL		
		Bedrock	Soils	
			Coarse Grained Soil	Fine Grained Soil
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	Rotational	Rock slide	Debris slide	Earth slide
	Translational			
Lateral spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow	Debris flow	Earth flow
Complex: Combination of two or more types of movement				

How to Identify Landslide Hazards

Prediction or identification of a landslide is an area is essential to minimize or control intensity of landslide hazard. Usually it is done using costly procedures as surveying, monitoring, or soil testing, which are not affordable or feasible in rural areas with very little resources. Therefore, simpler, but still effective methods are to be used for assessing the stability of a slope or to decide if a given location is safe for construction. Two sources of useful information will be presented here: terrain morphology and landslide risk indicators.

Terrain/Morphological Features Indicating Risk for Occurrence of Landslide

Steep slopes*:* Terrain characteristics are very important for assessment of potential areas of landslide. Among them slope is most relevant. Construction on or at the base of steep slopes has to be done carefully. For any type of construction of steep slope with slope angles larger than 25 degrees, it is mandatory to make sure that the ground is reasonably stable.

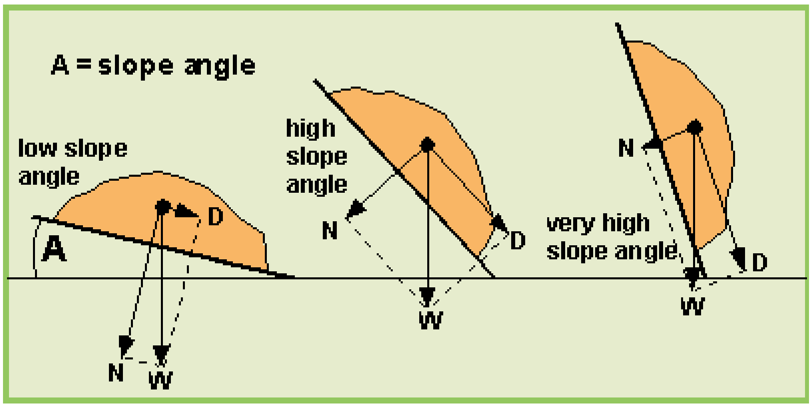

Fig. 2. An increasing slope angle A also results in an increase of the driving force D

Investigation of terrain of study area be done to find out occurrence of landslide in the recent past. The inherent stability of a slope depends on three factors: the soil texture, the slope angle, and the slope height. Slopes higher than 40 meters and with angles over 30 degrees should be avoided for any type of developmental activities if possible.

Old landslides/rock fall sites*:* construction on or near old landslide sites should be avoided for two reasons. Firstly, the old landslide can be reactivated, for example, by heavy rainfall or an earthquake. Second, because another landslide could occur at the same location as the previous one and slide down over the old landslide.

New cracks or unusual bulges in the ground or street pavements: Cracks on the ground surface are indicators that the ground is moving, either moving slowly (creep) or initiating a landslide. No construction should be under taken on or near such terrain without undertaking scientific remedial measures (which are often not feasible). The major risk indications for occurrence of landslides are:

(i) Sunken or down-dropped road beds,

(ii) Springs, or saturated ground in areas that have not typically been wet,

(iii) Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).

The additional landslide risk indicators are given as:

(i) Ancillary structures such as decks and patios tilting and or moving relative to the main house

(ii) Tilting or cracking of concrete floors and foundations

(iii) Soil moving away from foundations

(iv) Broken water lines and other underground utilities

(v) Leaning telephone poles, trees, retaining walls, or fences

(vi) Offset fence lines or retaining walls

(vii) New cracks or unusual bulges in the ground or street pavement

(viii) Sticking doors and windows, and visible open spaces indicating jambs and

In most cases in areas of potential landslide risk a combination of morphological and landslide risk indicators are considered for detailed analysis.

How to Minimize Landslide Hazards

Passive Intervention

(i) Choose a safe location to build your home,

(ii) Prevent deforestation and vegetation removal,

(iii) Avoid excavation causing weakening the slope.

Active Preventive Intervention

(i) Reforestation: Root systems bound materials together and plants prevent water percolation and take water up out of the slope.

(ii) Proper surface water runoff must be ensured, especially where houses and roads have disrupted the natural flow of water. It can be achieved by providing a proper canalization network.

(iii) Drainage: good ground drainage essential to prevent is saturation and consequent weakening. Adequate drainage is also needed when any kind of civil work, like retaining walls, has been constructed.

(iv) Nets are a common and cost-effective solution. However, it is still too costly (and technically complicated) to be used in small villages or to protect private homes.

(v) In addition, gabions can also effectively replaced the more expensive reinforced concrete retaining walls.

(vi) Proper construction practice: It is often the case when some landslide mitigation works are conducted but these are insufficient or not properly planned. The retaining wall constructed was insufficient for the earth pressures developed in rainy conditions.

Generation of input parameters for Landside Hazard Zonation under GIS environment

Drainage map, contour map, digital elevation model, slope angle map, land use/land cover map, relative relief map, thrust (buffer) map, photo-lineament (buffer) map, geological map are basic requirement for landslide hazard zonation or for identification of landslide prone areas which can be delineated under GIS environment using remote sensing data. The DEM represents spatial variation in altitude and used to generate slope and relative relief map. Slope is an important parameter for stability evaluating. It is the first derivative of elevation with each pixel denoting the angle of slope at a particular location. As the slope angle increases, shear stress in soil or other unconsolidated materials generally increases as well. With increase in vegetation, the stability of slope tends to increase, hence ratings were given accordingly. Relative relief is defined as the difference in maximum and minimum altitude within an area or facet and is calculated spatially. Higher relief values are more significant in causing landslides.

Landslide Hazard Zonation with special emphasis to Himalayan Region

Landslides are complex natural phenomena that are hard to model and simulate. Predicting hazardous events like landslides are particularly difficult because no laboratory exists that can preliminarily measure important variables, refine the techniques, and apply the results (*Dattilo and Spezzano, 2003*). Mitigation of disasters on account of landslides can be successful only with detailed knowledge about the expected frequency, character and magnitude of mass movements in an area. For forecasting occurrence of landslides in near future in an area, comprehensive knowledge of causative factors of land sliding is necessary.

Hence, the identification of landslide-prone regions is essential for carrying out quicker and safer mitigation programs, as well as future strategic planning for an area. Therefore, the Landslide Hazard Zonation (LHZ) of an area becomes significant whereby the area is classified into different LHZ ranging from very low hazard zone to very high hazard zone (*Arora et. al,. 2004*). Landslide susceptibility mapping is of great value for landslide hazard mitigation efforts (*Ercanoglu et al., 2004*). Landslide hazard analysis focuses mainly on the spatial zoning of the hazard (*Beek and Asch, 2004*).

Remotely sensed data are used in solving various environmental tasks. This technology can be used as an effective aid in natural hazard investigation, as well as for the purpose of environmental planning. Terrain information, such as, land cover, geology, geomorphology and drainage could also be derived from it and existing thematic information can be updated to enable the quantification of human interference on the earth's surface. Geographic Information System (GIS), as a computer- based system for data capture, input, manipulation, transformation, visualization, combination, querry, analysis, modeling and output, with its excellent spatial data processing capacity, has attracted sincere attention in natural disaster assessment.

The wet tropical and sub-tropical climate accompanied with humid condition favour disintegration of the top layer of soil through influence of several hydrological factors, soil conditions, topographic condition, which prevails in the most part of the eastern Himalaya region especially in Arunachal Pradesh, Meghalaya, Mizorum. With prevalent jhum cultivation practices, north-eastern Himalaya is more prone to soil erosion and degradation, which calls for sustainable management practices. Landform development in the Himalayan terrain is entirely different while comparing with Peninsular India of Pre-cambrian era. High relief, loose lithology, monsoon precipitation and intensive tectonic forces are highly influential for landform development in the Himalayan region. Within Himalayan ranges age of rocks differs from north to south, because of its episodic upliftment at different time interval vis-à-vis its origin. The Himalaya is undergoing rapid uplift at a rate between 0.5 and 4 mm per year and consequently experiencing rapid erosion causing deposition of thick pile of terrigeneous sequences (*Saha et al., 2002*).

Spatial and temporal thematic information derived from remote sensing, thematic maps and ground-based information needs to be integrated. Several researchers have envisaged remote sensing and GIS technologies for LHZ studies. Specifically GIS has the potential of performing Landslide Zonation using various thematic layers. A study has also been carried out (in a part of Garhwal Himalaya (Tehri environ) to know the spatio temporal dynamics of landslide using multi temporal remote sensing data (Pandey & Verma, 2007). To study temporal dynamics of landslides, satellite images of LISS-III and LISS-IV sensors for the year 1995 and 2005 were used (Plate 1). The total area effected from landslides hazard has been mapped in year 2005 with LISS III data and estimated to 2.93 sq. km which is greater than 1.3 sq. km of landslide area, mapped in the year 1995 with LISS-III data. In terms of landslide incidence the number of landslides in area increased from 134 during 1995 to 725 in 2005 indicating 81.51 percent of increase in landslide incidence area (Fig. 3). The number of landslides occurred during 1995 and 2005 were analyzed with reference to mapped terrain parameters to throw light on their genetic distribution in space and time. The decadal percent increase in landslides incidences have been calculated to understand the gravity of landslides incidence over various landslide inducing terrain parameters. Majority of the landuse/landcover classes have witnessed a decadal percent increase in landslide incidence by less than 50 percent. It is interesting to note that no increase has been noticed over degraded forests whereas the highest increase is observed over agricultural land (86.7%). High increase in agricultural areas could be attributed to anthropogenic activities, low vegetation cover during no crop periods and high sheet erosion during heavy rainfall periods (*Pandey* & *Verma, 2007*).

In the assessment of risk associated with landslide movement, the likelihood of slope failure is of prime interest (*Chen et al., 2003*). Over the past two decades, many scientists have attempted to assess landslide hazards and produced susceptibility maps portraying their spatial distribution. However, there has been no general agreement on the methods or even on the scope of these investigations. The key issue in forecasting landslide or other geological hazards is the identification and collection of the relevant predictors whose nature, character and role vary depending on the type of disaster and geological, geomorphological and climatic setting of the region affected by the extreme event (*Carrara et al., 1999*).

According to *Van Westen et al.* (1999), LHZ can be broadly divided into two categories; (1) direct hazard mapping, in which the degree of hazard is determined by the mapping by geomorphologist, based on his experience and knowledge of the terrain conditions, and (2) Indirect hazard mapping, in which either statistical models or deterministic models are used to predict landslide prone areas, based on information obtained from the interrelation between landscape factors and the landslide distribution. A comprehensive understanding of the geomorphological evolution of an area, combined with a thorough and detailed mapping by geomorphologists is essential in order to derive a reliable hazard map. Whether it is decided to use a direct or indirect method, the geomorphological expertise of the person collecting the data is crucial. The various causative factors in the form of thematic layers were integrated and analyzed in a GIS environment to derive LHZ map. Various methods of data integration for LHZ have been reviewed by Van Westen (1994). Some of the important methods are: (1) landslide spatial distribution analysis providing information on the occurrences of landslides, (2) the ordinal scale (quantitative) approach using weighting-rating system of terrain parameters (ground-based knowledge) and (3) the statistical method, which finds suitability for small areas with detailed information. On account of limited availability of field data, the quantitative approach can be adopted for LHZ in the Himalaya region.

Landslide hazard zonation in southern Mizoram was carried out with the aid of geocoded IRS imageries and toposheet (GSI, North Eastern Region, 1999). The work resulted in delineation of the entire region into low hazard zone (30%), medium hazard zone (60%) and high hazard zone (10%). The critical part containing the high hazard zone was also identified where detailed information regarding geology, tectonics, engineering properties of slope material and land use pattern would be incorporated for evaluation of specific locations. Landslide hazard zonation has been attempted using GIS techniques by manipulation and interrelating geomorphic, geologic and meteorological variants of Lawngtlai area, which is a known landslide prone area of Mizoram (Plate 2 and Fig. 4). This methodology involves preparation of different thematic maps, viz. slide incidence map, equal landslide area map, slope map, drainage map and then merging of two or three themes to generate composite maps, Finally, each of these composite maps was interpreted to arrive at a final hazard zonation (Fig. 5). There is a fairly high degree of matching in the high risk zone area (39.8%) and stable zone (60.2%).

Plate 1a and b: Field Photographs of major landslide zone in Tehri region (Uttarakhand)

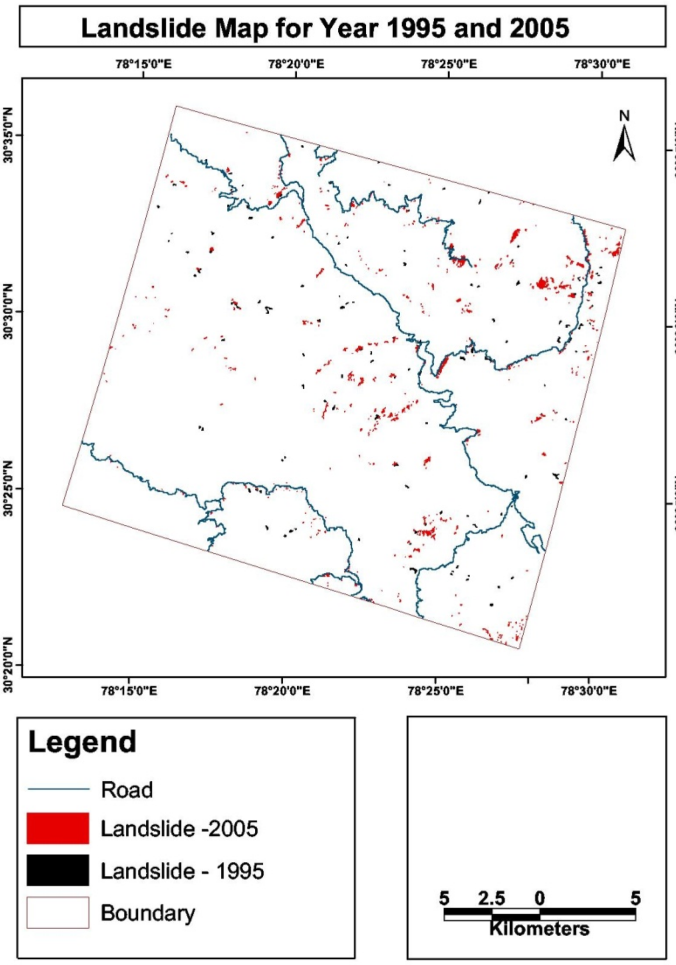

Fig. 3. Area effected from landslide in the year 1995 and 2005.

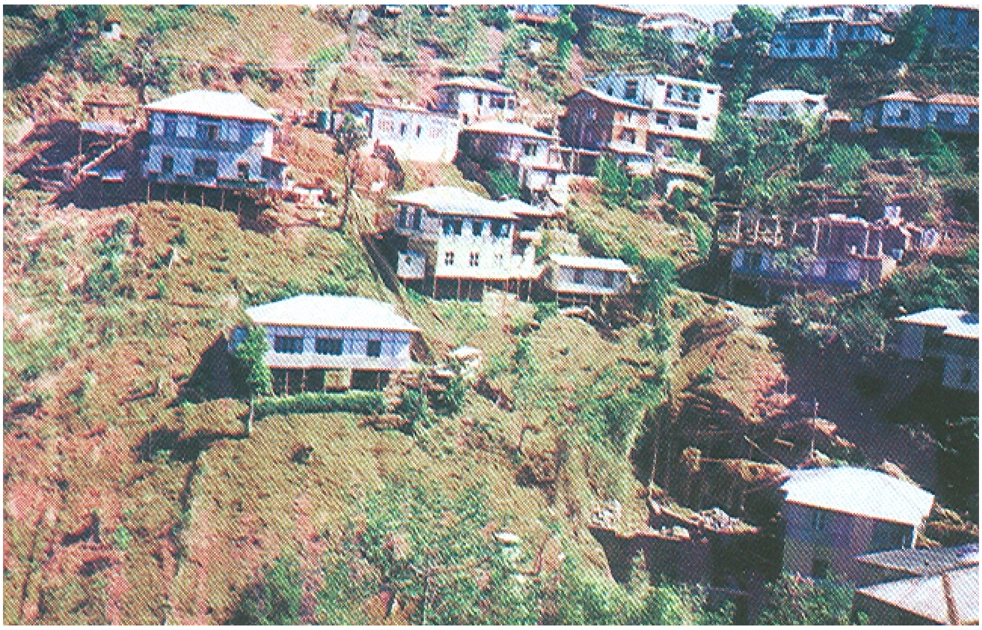

Plate 2: Unplanned housing on landslide prone slopes in Lawngtlai area, Mizoram

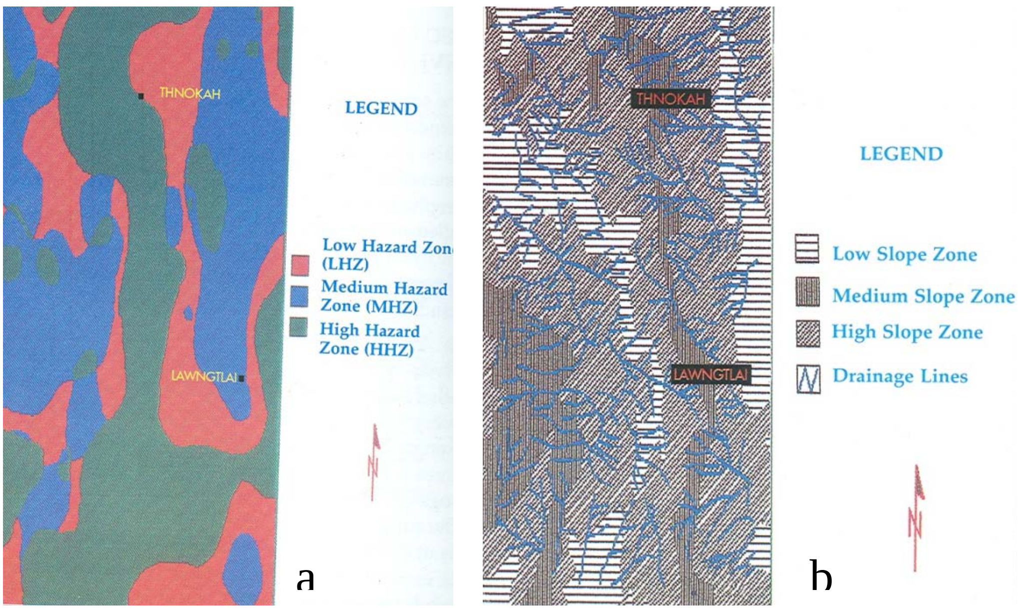

Fig. 4 a and b. Slope and drainage map and Landslide Hazard zonation (LHZ) map in Lawngtlai area, Mizoram

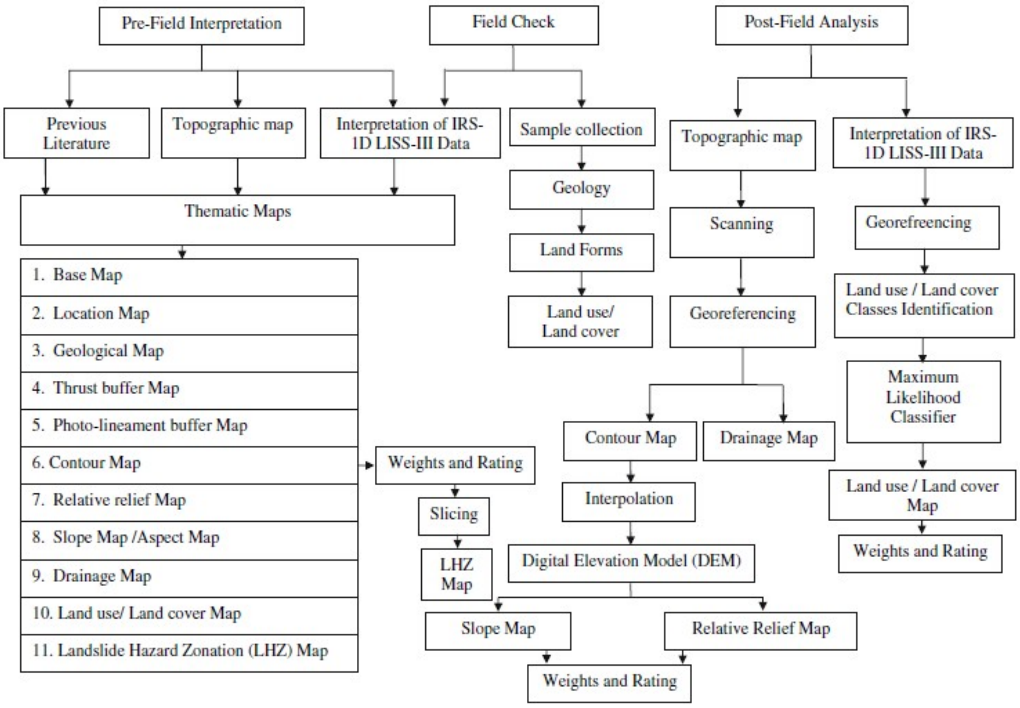

Fig. 5. Detail methodology used for Landslide Hazard Zonation

According to Onagh *et. al.* land use is also one of the key factors responsible for the occurrence of landslides, since, barren slopes are more prone to landslides. In contrast, vegetative areas tend to reduce the action of climatic agents such as rain, temperature etc., thereby preventing erosion due to the natural anchorage provided by the tree roots and, thus, are less prone to landslides. The main goal of this study was assessment and appraisal of the Multiple Linear Regression modelling method in landslide susceptibility zonation and validation of landslide susceptibility map with inventory map of study area. In this study, it is found that multiple linear regression model hazard map is able to predict 76.2 percent of all the landslides occurred in the study area. Thus, it could be concluded that Multiple Linear Regression approach could also be useful in relatively moderate and small areas. This study also concludes that the approach of GIS based modelling can give good results in the analysis of field-oriented data. The validation results showed satisfactory agreement between the susceptibility map and the existing data on landslide locations. As a result, the success rate of the model (76.2%) shows high accuracy in prediction. Landslide susceptibility index map of study area has been classified into four categories of landslide susceptibility: low, moderate, high and very high, on the basis of distribution of landslide inventory of the area. It shows the validity of the system adopted to divide the landslide susceptibility index map. Moreover, planning of any project at a local level requires large scale and more accurate landslide susceptibility mapping. Landslide susceptibility mapping at a small catchment scale covers a lot of information that is necessary for micro level planning. On the basis of landslides susceptibility, use of land for different purposes may also be decided.

Conclusion

Landslides, ground settlement and avalanche interfere greatly and persistently with mass activities. It occurs when hill side or valley side slopes falls using to specific geological, climatic and biotic factors. They are bringing about major disruptions of towns and cities, communication systems and large structure including dams and bridges. Slope plays a dominant role to create gravity force for wasting process like landsliding, soil creeping, slumping etc. Construction activities for development in Himalayan region have greatly enhanced the frequency of landslides. Mitigation of disasters due to landslides can be successful only with detailed knowledge about the expected frequency, character and magnitude of mass movements in an area. To forecast possibilities of the future landslides in an area, comprehensive knowledge of causative factors of land sliding is necessary. The wide applicability of geospatial technologies are using in solving various environmental tasks. This technology can be used as an effective aid in natural hazard investigation, as well as for the purpose of environmental planning. Drainage map, contour map, digital elevation model, slope angle map, land use / land cover map, relative relief map, thrust (buffer) map, photo-lineament (buffer) map, geological map are basic requirement for landslide hazard zonation or for identification of landslide prone areas which can be delineated under GIS environment using remote sensing data. Geographic Information System (GIS), as a computer- based system for data capture, input, manipulation, transformation, visualization, combination, querry, analysis, modeling and output, with its excellent spatial data processing capacity, has attracted great attention in natural disaster assessment.

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