

CHAPTER 3

LANDSLIDE HAZARD ZONATION

3.1 GENERAL

Landslide hazard is commonly shown on maps, which display the spatial distribution of hazard classes (Landslide Hazard Zonation). Landslide hazard zonation refers to “the division of the land in homogeneous areas or domains and their ranking according to degrees of actual / potential hazard caused by mass movement” (Varnes 1984).

Landslide failures have caused untold number of casualties and huge economic losses. In many countries, economic losses due to landslides are great and apparently are growing as development expands into unstable hillside areas under the pressure of expanding populations. In spite of improvements in recognition, prediction, and mitigation measures, worldwide landslide activity is increasing. The factors causing this expected augmented activity are

- Increased urbanization and development in landslide prone areas.
- Continued deforestation of landslide prone areas, and
- Increased regional precipitation caused by changing climate patterns.

According to Brabb (1993) at least 90 % of landslide losses can be avoidable if the problem is recognized before the development or deforestation begins. Hence, there is a dire need for identification of existing and potential unstable slopes. In this chapter more emphasis has been given to review the past studies on LHZ mapping by various approaches using Remote Sensing and GIS.

3.2 DEFINITION OF HAZARD, VULNERABILITY AND RISK

It is important to distinguish between the terms disaster and hazard. A potentially damaging phenomenon (hazard), such as earthquake, landslide by itself is not considered a disaster when it occurs in uninhabited areas. It is called a disaster when it occurs in a densely populated area, and results in a large destruction.

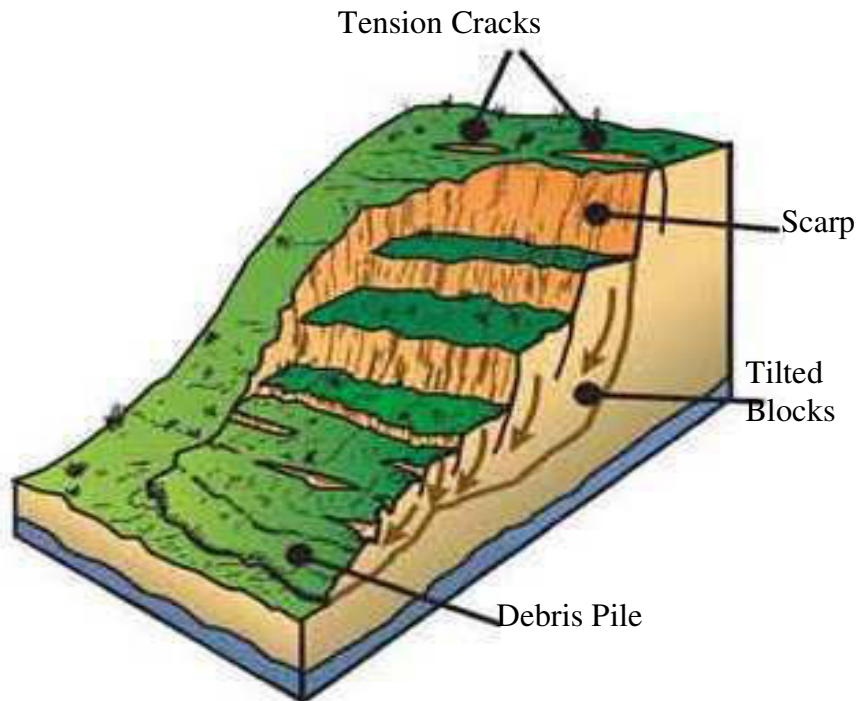


Figure 3.1 Landslide Hazard

The assessment of hazard, vulnerability and risk forms a crucial element in landslide. The following definitions of hazard, vulnerability and risk given by Varnes (1984) become generally accepted (Figure 3.1 and 3.2).



Figure 3.2 Vulnerability and risk illustrated using an example of elements at risk (road, pipelines, people and buildings) in a landslide area

Natural Hazard (H): the probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area.

Vulnerability (V): the degree of loss to a given element or set of element at risk (see below) resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss).

Specific Risk (Rs): the expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of H and V.

Element at Risk (E): the population, properties, economic activities, including public service, etc., at risk in a given area.

Total Risk (Rt): the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon. It is therefore the product of specific risk (Rs) and elements at risk (E) gives the total risk as given in equation (3.1)

$$Rt = (E) * (Rs) = (E) * (H * V) \quad (3.1)$$

3.3 HAZARD EVALUATION FACTORS

When assessing the probability of landsliding within a specified period of time and within a given area, recognition of the conditions that caused the slope to become unstable and the processes that triggered the movement is of primary importance. It is well known that many factors play an important role in engineering slope failure (Radbruch-Hall and Varnes (1976), Varnes (1984). The thematic inputs which determine the probability of landsliding for a particular slope or an area may be grouped into two categories called the preparatory factors and the triggered factors.

The preparatory factors, which make the slope susceptible to failure without actually initiating it and thereby tending to place the slope in a

marginally stable state, such as geology, structures, slope and aspect, relative relief, geomorphology, soil, drainage pattern, landuse/landcover (Dai et al 2002a).

The triggering factors shift the slope from a marginally stable to an unstable state and thereby initiating failure in an area of given susceptibility, such as heavy rainfall and earthquake (Wu and Siddle 1995). For this study, rainfall triggering factors is also taken into account to map the landslide susceptibility.

Geology

Geological and topographical parameters play a dominant role in the prognosis of landslide. It is appropriate to model these parameters for accurately delineating the hazard prone areas. In Nilgiris district most of the area exposes charnockite group of rocks with associated migmatites and Bhavani group along with enclaves of satyamangalam schist complex. This has been referred with geological map of GSI on 1:250,000 scale.

Geological structures play a crucial role for landslides. It is generally observed that landslides occur commonly along the major lineaments in the Nilgiris. Faults are more important for landslides. Hence, lineaments and faults in general, are considered as significant geological structures for landslide hazard zonation. The lineaments and faults are mapped from geological map of GSI on 1:250,000 scale and further lineaments are inferred from high resolution satellite imagery on 12,500 scale.

Slope

The topographical parameters like slope, aspect and relative relief play a significant role in landslide. Slope maps define slope categories on the

basis of the frequency of particular angles of slope. The distribution of the slope categories is dependent on the geomorphological history of the area. The angle of slope of each unit is a reflection of a series of localized processes and controls, which has been imposed on the facet. It is observed that slope greater than 25° is significant for the landslide.

Aspect

Aspect identifies the down-slope direction of the maximum rate of change in value from each cell to its neighbours. (Aspect can be thought of as the slope direction). The values of the output raster will be the compass direction of the aspect as shown in Figure 3.3. Hence, the aspect has been derived through TIN (Triangular Irregular Network) Module.

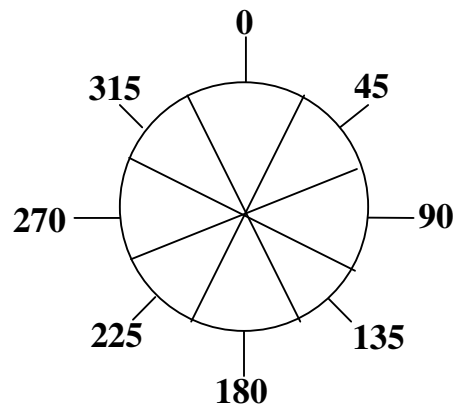


Figure 3.3 Compass Direction

Landuse and Land cover

The present day landuse has an important bearing for LHZ and mitigation measures. Land cover is an indirect indication of the stability of hill slopes. Barren and sparsely vegetated areas show faster erosion and greater instability as compared to reserve or protected forests, which are

thickly vegetated and generally less prone to mass wasting processes. Forest cover, in general, smothers the action of climatic agents on the climatic agents on the slopes and protects them from the effects of weathering and erosion. A well-spread root system increases the shearing resistance of slope material. Agriculture, in general, is practiced on low to very low slopes, though moderately steep slopes are not spared at places. However, the agricultural lands represent areas of repeated water charging for cultivation purposes and as such may be considered stable. Satellite data has the capability to directly record these features from the ground. The different density of vegetation, the rocky exposures, agricultural lands etc is mapped from the high-resolution satellite data on 1:12,500 scale.

Soil

The top regolith i.e. the soil has an important bearing on the landslides in the Nilgiris. The texture of the soil is important for such type of prognosis. The different texture types have been mapped for the study area in consultation with the soil survey report of Coonoor and Kothagiri Taluk and Soil Atlas – The Nilgiris District.

Structure

The geological structure plays a crucial role for landslides. It is generally observed that landslides occur commonly along the major lineaments in the Nilgiris. Faults are more important for landslides. Hence, lineaments and faults in general, are considered as significant geological structures for landslide hazard zonation. The lineaments and faults are mapped from geological map of GSI on 1:250,000 scale and further lineaments are inferred from high resolution satellite imagery on 12,500 scale.

Geomorphology

Geomorphology depicts the present morphological set-up. This is very important since some of the important geomorphic elements give us a clue for the future landslide in that area. The dissection pattern of hills like the highly dissected hill, moderately and low dissected hills helps in understanding the denudation chronology of the area. The role of denudation process in the landslide is very well known. The toe cutting by the river is an important denudation process, which triggers landslide. Hence, these toe cutting areas identified using ground and satellite data. Equally important is to identify areas, which have low hazard potential. This is useful for taking up developmental activity in such areas.

3.4 USES OF LANDSLIDE HAZARD ZONATION

The LHZ maps have multi uses, some of which are listed below.

- The LHZ maps identify and delineate unstable hazard-prone areas, so that environmental regeneration programmes can be initiated adopting suitable mitigation measures.
- These maps help planners to choose favorable locations for sitting development schemes such as townships, dams, roads and other developments.
- General purpose master plans and land use plans.
- Discouraging new development in hazard prone areas.
- Choice of optimum activity pattern based on risk zones.
- Quick decision making in rescue and relief operations.

Even if the hazardous areas cannot be avoided altogether, their recognition in the initial stages of planning may help to adopt suitable precautionary measures. Clearly such maps have a large number of users, including several government departments and private agencies as well as NGO's involved in any type of development, construction of disaster management work.

3.5 ASSUMPTION FOR LHZ

Landslide Hazard Zonation has been actively pursued for the last two decades and various methodologies are still being refined. Varnes (1984) has outlined three assumptions that form the basis of landslide hazard zonation.

1. It is considered that future slope failures are most likely to occur in geologic, geomorphologic and hydrologic situations that have led to past failures.
2. In a given study area the factors that cause landslides can be rated or weighted.
3. If conditions that promote instability can be identified, it is often possible to estimate their relative contribution and assign them some spatial quantitative index.

Thus, the degree of potential hazard in the area can be estimated depending on the number of failure inducing factors present in a given locality. Since GIS are efficient tools for managing and analyzing spatial data, it can be used to develop hazard zonation model based on the above assumptions.

3.6 MAPPING SCALE FOR LANDSLIDE HAZARD ANALYSIS

The amount and type of data has to be stored in a GIS for landslide management depends very much on the level of application, or the scale of the project management.

Natural hazards information should be included routinely in development planning and investment project preparation. Development and investment projects should include a cost / benefit analysis of investing in hazard mitigation measures, and weigh them against the losses that are likely to occur if these measures are not taken (OAS / DRDE 1990).

Selecting the working scale for a slope instability analysis is determined by the purpose for which it is executed. The following scales of analysis, which were presented in the International Association of Engineering Geologist's (IAEG 1976) monograph on engineering geology, can also be distinguished in landslide hazard zonation.

- National Scale (<1:1000,000)
- Regional and Synoptic Scale (1:100,000 – 1:1000,000)
- Medium Scale (1:25,000 – 1:50,000)
- Large Scale (1:5,000 – 1:15,000)
- Site investigation Scale (>1:2,000)

The national hazard zonation mapping scale is intended to give a general inventory of problem areas for an entire country that can be used to inform national policy makers and the general public. The level of detail will be low.

The regional mapping scale is mean for planners in the early phases of regional development projects or for engineers evaluating possible constraints due to instability in the development of large engineering projects and regional development plans.

Medium scale hazard maps can be used for the determination of hazard zones in areas affected by large engineering structures, roads and urbanization.

The level of application is typically that of a municipality. The use of GIS at this level is intended for planners to formulate projects at feasibility levels. At this level, the hazard maps are produced mainly for authority dealing with detailed planning of infrastructural, housing, or industrial projects, or with evaluation of risk.

At site investigation scale, the hazard maps are made to plan and design of engineering structures (buildings, bridges, roads etc), and in detailed engineering measures to mitigate natural hazards (retaining walls, check dams etc.)

3.7 METHODS FOR LANDSLIDE HAZARD ZONATION

In the recent past, various methods and techniques have been proposed to analyze the causative factors of landslides and produce maps portraying the probability of occurrences of similar phenomena in future. Hansen (1984), Varnes (1984), Van Westen (1993), Soeters and Van Westen (1996) and Van Westen et al (1997) divided these methods into direct and indirect (Figure 3.4). A brief outline of different methods (NRSA 2001) is described below.

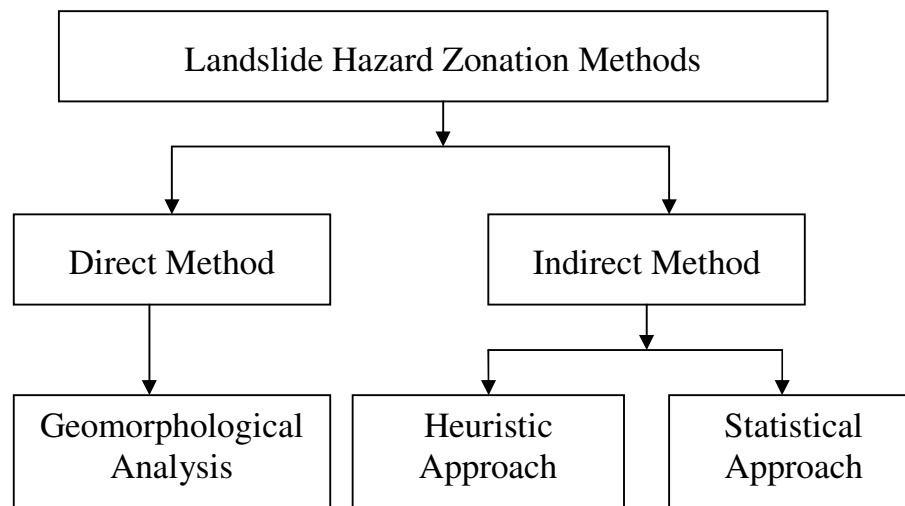


Figure 3.4 Approaches for LHZ

3.7.1 Direct Method

The direct method consists of Geomorphological mapping where the earth scientist evaluates the direct relationship between the hazard and the environmental setting during the survey at the site if the hazard event. The basis for this approach was outlined by Kienholz (1977), who developed a method to produce a combined hazard map based on the mapping of silent witnesses. The process is based on the past and present landslides are identified and expert opinion of those sites where failures are most likely to occur and he has used reasoning of analogy. The decision rules are therefore difficult to formulate, as they vary from place to place. It does not require the digitizing of many different maps. However, the detailed fieldwork requires a considerable amount of time as well. The accuracy of the resulting hazard map will depend completely on the skill and experience of the geomorphologist. Geomorphological maps of the same area made by different geomorphologist may vary considerably. GIS is generally not used as analysis tool, but merely as data management tool.

A number of methodologies for landslide susceptibility zonation have been proposed which can be grouped into six categories (Table 3.1). The simplest of all, the distribution analysis only depicts direct mapping of landslide locations from field surveys or aerial photographic interpretation. Thus do not provide information on predictive behavior of future landslide activity.

In this type of analysis, GIS is used to digitize landslides prepared from field survey maps, aerial photographs and remote sensing images. In qualitative analysis, subjective decision rules are applied to define weights and its ratings based on the experience of experts (Saha et al 2002).

The logical analytical method proposed by Bughi et al (1996) is a variation of the above, where the field survey data on slope deformation helps to decide the numerical weights. Remote sensing and GIS techniques may be utilized here for thematic map preparation and overlay analysis.

This study aim at improve our knowledge about the frequency, magnitude and types of landslides in Nilgiris and the possibilities of producing landslide risk assessment at different levels. The research is intended to contribute in reducing the lack of knowledge about landslide assessment problems mentioned herein, as well as in applying innovative spatial analysis for landslide risk assessment at different scales, by taking into account the specific situation with respect to data availability. Before the objectives of this study are defined, an overview of the most important research problems related to landslide risk assessment is presented below.

Table 3.1 Methodologies for various landslide hazard/susceptibility zonations (after van Westen 1994, Mantovani 1996)

LHZ/LSZ method		Main feature	For example
Qualitative	Distribution analysis	Direct mapping of mass movement features resulting in a map, which gives information only for those sites where landslides have occurred in the past	Wieczorek (1984)
	Qualitative analysis	Direct or semi-direct methods in which the geomorphological map is renumbered to a hazard / susceptibility map or in which several maps are combined into one using subjective decision rules based on the experience of the earth scientist	Saha et al (2002)
Quantitative	Statistical analysis	Indirect method in which statistical analysis are used to obtain predictions of the mass-movement from a number of parameter maps	Yin and Yan (1988), Gupta and Joshi (1990), Lee et al (2002), Ayalew et al (2004)
	Distribution-free methods	Neuro-fuzzy methods, which do not depend on distributional assumptions of the data. Here, the weights are computed in an objective manner	Arora et al (2004), Elias and Bandis (2000)
	Deterministic analysis	Indirect methods in which parameters are combined in slope stability calculation	Okimura and Kawatani (1986)
	Landslide frequency analysis	Indirect methods in which earthquakes and/or rainfall records or hydrological models are used for correlation with known landslide dates to obtain threshold values with a certain frequency	Capecchi and Focardi (1988)

3.7.2 Indirect Method

The indirect method includes two different approaches, namely the heuristic (knowledge driven) and Statistical (data driven) techniques. To overcome the problem of the “hidden rules” in geomorphological mapping, heuristic approach has been developed based on factors influencing landslides, such as rock type, slope, landform, landuse etc. In heuristic approach, the earth scientist uses the expert knowledge of an individual to assign weightage values to the series of parameter maps. The terrain conditions of a large number of locations are summed according to these weights, leading to hazard values, which can be grouped into hazard classes. This is normally based on ‘apriori’ knowledge available to the experts on causes of landslides in the particular area of investigation.

Stevenson (1997) developed an empirical hazard rating system for an area in Tasmania. On the basis of his expert knowledge on the caused factors of slope instability, he assigned weighting values to different classes in a number of parameter maps. This method of qualitative map combination has become very popular in slope instability zonation.

This method is applicable on all three scales. Each scale has its own requirements as to the required details of the inputs.

In statistical landslide hazard analysis, the combination of factors that have led to landslides occurrence in the past, are determined statistically and qualitative predictions are made for landslide free areas with similar conditions.

3.8 BASIS OF SPATIAL LANDSLIDE HAZARD MAPPING

The ultimate goal of landslide hazard mapping studies is to protect the population, the economy and the environment against potential damage caused by landslides. This requires an accurate assessment of the level of threat from a landslide: an objective reproducible, justifiable and meaningful measure of risk (Crozier and Glade 2005). Risk, in this context, is seen as a disaster that could happen in the future. Considering this relationship, it is evident that an accurate assessment model is of the utmost importance as it may under- or over-estimate the occurrence of future events. However, there is not yet a common agreement on risk assessment at least for landslide disasters and still many issues on methods and data remain partially under research. It is also relevant the spatial dimension of risk which depend on locations and on scales in which the assessment is carried out. Taking into account of the importance and characteristics for disaster reduction, the investigations on risk assessment has increased enormously in the last decade.

The international call for risk assessment became more evident after the World Conference on Disaster Reduction (United Nations, 2005b) in Kobe, where one of the gaps identified from the Yokohama Strategy was 'Risk identification, assessment, monitoring and early warning'. With the expected outcome of a 'substantial reduction of disaster losses' the Conference proposed the so called 'Hyogo Framework for Action 2005-2015' (United Nations, 2005a) which includes three strategy goals and five priorities as actions. The second priority for action was: 'Identify, assess, monitor disaster risks and enhance early warning' with the following key activities:

- Develop, update periodically and widely disseminate risk maps and information related to decision-makers, general public and communities at risk in an appropriate format.

- Develop system of indicators of disaster risk and vulnerability at national and sub-national scales. This system will enable decision-makers to assess the impact of disasters on social, economic and environmental conditions and to disseminate the results for the decision makers, public and populations at risk.
- Record, analyze, summarize and disseminate statistical information on disaster occurrences, impacts and losses, on a regular basis through international, national, regional and local mechanisms.

The recognition of updating, dissemination and format for risk maps are important issues in this context. They highlight the need for working at different levels, to search for appropriate indicators and the relevance of disaster inventory. Although the needs were clear the methods for implementation were not, forcing the scientific community to find methods for risk assessment per type of hazard, such as landslides contributing to a multi-hazard approach. As a consequence, the scientific community of disaster type started to develop their own framework and generally discussing assessment methods, monitoring, early warning and management.

To remove subjectivity in qualitative analysis, various statistical methods have been employed for LSZ studies. These methods can be broadly classified into three types: bivariate, multivariate and probabilistic prediction models. The bivariate models consider each individual thematic map in terms of landslide distribution and can be easily implemented in GIS (Van Westen 1997). The Information Value (InfoVal) Yin and Yan 1988 and Landslide Nominal Risk Factor (LNRF) method (Gupta and Joshi, 1990) are bivariate statistical analyses which are used to prepare landslide susceptibility maps. Multivariate methods consider various thematic at once into a complex and time-consuming data analysis processes (Carrara et al 1991). The probabilistic

prediction models (Chung and Fabbri 1999) provide quantitative estimates of future landslide activity based on prediction from past events.

The ‘weight of evidence’ approach is also a kind of bivariate analysis utilizing Bayesian probability model (Lee et al 2002). During the last 5 years, distribution-free method such as neuro-fuzzy analysis (Elias and Bandis 2000) also implemented for LSZ studies. In addition to this, deterministic and landslide frequency analysis methods are also been reported for site-specific studies on landslides.

For medium-scale regional LSZ studies, the methods based on qualitative and statistical analysis have been more commonly used. Qualitative methods have the disadvantage of utilizing opinion-based weights. Therefore, to introduce objectivity in weight assignment and landslide susceptibility zoning, statistical analysis is appropriate.

Landslide occurs in mountainous terrains during and after heavy rainfall. Steep terrain and high frequency of rainfall make landslide occurrence frequent on natural terrain (Dai and Lee 2002). Geotechnical and terrain features that influence landslides are cohesion, angle of internal friction, slope and relative height, orientation of slope (aspect), proximity to drainage, vegetation cover and proximity to major faults (Gokceoglu and Aksoy 1996). Intense rainfall coupled with the increase in human activities associated with urban development which has contributed to increase instability of slopes. In the Indian sub-continent, landslides are known in three major regions namely, the Himalayas in north and north east, Western Ghats in the south west and the Nilgiris in the south. The major factors behind these landslides are active tectonics in the Himalayan landslides, slope erosion and rock fall in the Western Ghats and rainfall in the Nilgiris (Seshagiri et al 1982).

Landslide is a frequently occurring phenomenon in the Nilgiris district because of high intensity rainfall. Landslides occur both in remote, unpopulated as well as in the populated regions. Most of the landslides occur in places where deforestation, plantation, urbanization, shifting cultivation, infrastructure developmental activities etc. takes place. In such places, infiltration is high and landslides occurred because various soil layers, such as pervious and impervious layers are predominant, and also thickness of soil is high.

Severe and major landslides occurred during 1978, when more than 100 landslides were recorded within an area of 250 km². In 1979, more than 200 landslides were reported in the same area. In 1992, a number of landslides occurred, causing damages to the roads and private properties in the Coonoor region. During 1993, about 408 landslides have been reported, of which Marapalam area of the Coonoor region is the most severe one (Balachandran et al 1996). The major triggering factors of landslides in Nilgiris are inadequate drainage, more soil thickness, deforestation, improper landuse practices, and disturbance of natural topography by anthropogenic activities.

A number of studies have been carried out in the area by various agencies with different approaches (Seshagiri et al 1982). A case study of debris avalanche at Marappalam in Nilgiris district was reported by Balachandran et al (1996). These studies not analyzed the contributing factors with proper weights. Geographical Information System (GIS) is an ideal tool for integrating remote sensing image data as well as collateral data. Hence GIS is used in this study for preparation of data layers to each theme. Collection of various data is a tedious, time consuming and costly affair. Hence, remote sensing data are used and landuse / landcover map has been

prepared from IRS IC LISS III imagery within a reasonable time and cost but with high accuracy.

The main goal of the analysis of landslide susceptibility is to reduce the impact of landslides by determining the areas at risk. Natural hazard mapping includes the formation of natural events such as landslide, flood, earthquake, and volcanic eruption that happened in the past and estimated their future occurrence. There is a rapid progress in the preparation of landslide susceptibility maps because of the development in technology. Geographical Information Systems and Remote Sensing techniques have proved to be very valued in preparing these kinds of maps. Data is easily gathered and analyzed using RS techniques, according to mathematical and statistical criteria, it is possible to store, process, and analyze a large amount of complex data easily in a very short time using GIS techniques.

Preparation of landslide inventory and susceptibility maps is one of the most important stages in landslide hazard mitigation. These maps provide important information to support decisions for urban development and land use planning. Also, effective utilization of these maps can considerably reduce the damage potential and other cost effects of landslides. However, landslides and their consequences are still a great problem for many countries, particularly in India due to rapidly increasing populations. We are facing the problems arising from increasing demand for urban lands. At the same time as their limited financial resources hinder mitigation efforts, which should be performed before the landslide event occurs.

To date, a number of different methods have been developed to predict landslide hazards. They can be divided into two groups as qualitative methods and quantitative methods. These vary from experience-based analyses to complex mathematical, logical, and/or computer-based systems to analyze landslide susceptibility, hazard, and risk. Geomorphological analyses

and direct field mapping methods are considered as qualitative methods because they don't yield numeric output with reference to landslide assessment. On the other hand, quantitative methods such as deterministic analyses, probabilistic approaches, statistical methods, and artificial intelligence techniques closely rely on mathematical models and produce numeric outputs. However, no general agreement has been reached yet about the best method for producing landslide hazard assessment maps. Although all known methods have their own advantages and disadvantages, utilization of quantitative methods has become preferred and more commonly used in recent years.

Landslides constitute one of the major natural catastrophes, which accounts for considerable loss of life and damage to communication routes, human settlements, agricultural and forestland. Most of the terrain in mountainous areas have been subjected to slope failures under the influence of variety of terrain factors and figured by events such as extreme rainfall or earthquake.

In India, landslides are occurring frequently in Himalayan region mainly in North and Western Ghats in South. Advancement in remote sensing technology enables us to identify the finer features on the terrain and to create high resolution Digital Elevation Model (DEM). Most of the landslide modeling using GIS involves contour interval of 20 meters or 10 meters. The thematic maps generated from remote sensing data of resolution 30 and 5.8 meters. This research work evaluates the landslide hazard zonation using different kinds of spatial data (aerial photographs, satellite imagery) and also discusses the technological improvements in remote sensing sensors which greatly influence the accuracy of Landslide Hazard Zonation mapping. Remote sensing and GIS plays a very important role in preparation of LHZ. Many thematic maps such as geology, geological structures, landforms, land use/land cover, slope, drainage, and aspect are needed for this purpose.