CHAPTER 3

LITERATURE REVIEW

3.1 INTRODUCTION

Geological hazards involve death, damage to property, and disruption of communication, sanitation, and transportation systems. Geoscientists and environmental scientists therefore must know the probable locations, causes, and impact of hazards, so that appropriate remedial or mitigation measures are provided to prevent or minimize the impact of hazards. Geological investigation in Nagaland and landslides in particular is very scanty because of its remoteness, inaccessibility and hilly terrain. Oldham in 1883 discussed the geology of Kohima and parts of northern Manipur. Pascoe (1912) described the geology between Dimapur and Saramati. Evans in 1932 gave an account of the Tertiary succession of Assam including Nagaland. Later on in 1964, Mathur and Evans studied the stratigraphy, structure, and conditions of deposition of the Tertiaries of Upper Assam and Nagaland. The first attempt of landslide studies was conducted by Sondhi V.P in 1941 along the Dimapur-Manipur road. Sharda & Bambay (1980) prepared geotechnical and slope classification maps of Kohima Town. They also conducted Environmental and Geotechnical/Geoscientific studies of the same area. Anand (1988) conducted preliminary geological investigations of landslides along the Dimapur-Mao section. Verma (1990) carried out some landslide investigation in Nagaland along Kohima-Meluri road. In 1996, Directorate of Geology & Mining, Nagaland conducted a study on the feasibility of groundwater development in and around Kohima Town. Lotha (1994) investigated some landslides of Kohima. Bhattacharjee et al (1998) also added to landslide literature by their investigations of land instability along National Highway 39. The Central Road Research Institute (2000) has carried out some landslide investigation along the National highway 39 between Chumukedima and Maram.
Landslides are comparatively less studied than other geological activities or hazards such as earthquakes, volcanoes, and floods. In the past landslides were either not given due importance or attempted to be controlled using unscientific means. Today, however, landslide investigations are receiving increased support from governmental agencies as well as the general public. This stems from the growing awareness of their destructive potential. Zoning laws, grading ordinances, and environmental impact statements are becoming more common and reflect the increased level of sophistication in the public understanding of earth phenomena. Mapping of landslides and landslide-prone topography is being done on both the regional as well as local scales. Landslides may occur suddenly or through a prolonged period of time, with or without any apparent provocation. Every mass beneath a slope has a tendency to slide downward and outward under the influence of gravity. If the shear strength of the soil adequately counters this tendency the slope is stable. It is an annual and recurring phenomenon, particularly in hilly terrain and most commonly occurs during the monsoon. Developmental activities such as construction of roads, dams, buildings, and exploitation of natural resources in an unscientific manner have further aggravated the problem. Basically there are two different categories of landslides. The first comprises those slides that have occurred due to purely mechanical causes, e.g., increase of hydrostatic pressure and erosion. The second category includes those slides that have been caused by changes in the physical and/or chemical properties of the soil. In most cases a gradual or sudden decrease of shear strength in a soil is due to the content of clay minerals. The clay minerals are responsible for the effects and the mechanism of water absorption, desorption, ion exchange, swelling, etc (Veder and Hilbert, 1980). Terzaghi (1950) opines that where silt is interbedded with sand, or clay is interbedded with silt, water percolating through the coarser, more permeable units gets trapped above the fine grained units. The resultant increase in positive pore pressure between the sand and silt grains forces the particles apart, reducing inter-grain friction. As gravitational forces acting on the grains are countered by increased buoyancy, the particles formerly stable on steep slopes, generally greater than 30°, becomes less stable, causing slope failure.
Sharma et al (1996) state that landslides are those events or forces that are amongst the most rapid of all mass movements. Landslides pose some of the greatest hazards in mountainous terrain. Landslides are common where the terrain is young, particularly in active mountain belts. One of the most important factors causing destructive landslides is road construction. Many of the roads have been unimaginatively planned and their construction very badly executed, leading to destabilization of hillsides and production of large amounts of debris (Valdiya, 1987). Ives (1987) states that most road construction in the Himalayas is substandard, which has led to greatly increased incidences of landslides.

Nilsen et al, (1976) states that many factors in combination are responsible for landslides which can occur as a result of sudden or gradual changes on a slope including the types and properties of underlying bedrock, soils and surficial deposits, angle and direction of slope, type of vegetation, amount and distribution of rainfall, type of construction, placement of cuts and fills, and the presence of ancient landslide deposits. Sahai (1993) states that lithology, slope, lack of vegetative cover, and unusual behaviour of rainfall pattern bring about instability of slopes. Landslides may be due to endogenous or exogenous processes. Landslides also occur as consequences of changes in landforms. They can be grouped into three categories including those that are unpredictable, those whose threat is known, and those that occur because of developmental projects. Certain management activities including clearing of forests and road construction are commonly perceived as potential landslide initiators (Gray, 1973; Swanson and Dyrness, 1975; Swanston and Swanson, 1977). Bhandari (1987) too insists that the frequency and gravity of the problem is due to man’s intrusion into the ecosystem.

Rock falls are considered to be discrete events involving the movement of blocks of debris due to gravity. However, most landslides are not single discrete events. Debris flows may be considered as any fluid failure, including mudflows and debris avalanches. Complex landslides that involve both rotational failure and penecontemporaneous wet flowage are termed slumps (Varnes, 1958). Slumps are also complex features involving the sagging, oozing, slipping, and sometimes rotation of
rocks and/or soils (Haigh, 1988). Slope angle, an important parameter in control of the
distribution of slides, reflects the increasing down-slope component of weight on
steeper slopes (Skempton and Delory, 1957). The coarse deposits associated with
debris slides lose their cohesion due to abundance of water and removal of the clays
and hence, are unstable on steep slopes.

Creep and subsidence are very slow movements. They generally affect entire hill
slopes or large areas. Their locus of displacement is usually a transitional zone rather
than a sharply defined shear surface. Creep is mainly due to the alternating shrinkage
and swelling of soils underlying slopes. There are two main types of creep, continuous
and seasonal. The continuous type refers to a relatively deep movement produced by
the force of gravity, often caused by the presence of various strata with different
elastic properties which creep beyond their yield strength. The seasonal type of
movement refers to relatively shallow failure related to changes in moisture and
temperature. Subsidence is a gravity phenomenon marking a very slow event that also
involves collapse but does not have a free exterior surface for movement (Sharma et
al, 1996).

Nagaland, a young mountainous terrain is highly dissected and relatively immature.
This area is part of the mobile morphotectonic unit of the Indian Plate that has
collided with the Burmese Plate (Bhattacharjee, 1991). It is for this reason that this
area is highly disturbed. The area of investigation is fallen under mountainous region
extending from Kohima to Pherima. The landslide incidences are relatively high along
the National Highway 39 between Kohima and Dimapur. This highway has been
affected by landslides ever since it was made motor-able. This highway runs through
diverse sedimentary terrain of Tertiary age. Very little systematic work has been done
on landslides and their social and economic impact in this area.

Landslides and mass movements are common phenomena in this fragile region which
is a geodynamically sensitive zone characterised by very extensive tectonic activity.
Tectonism has caused large scale folding and faulting that has resulted in crumpling
of the rocks. Folding is responsible for the tight anticlines and synclines at places in
the rocks of the area which have been further modified by the geomorphic processes. The erosional processes that dissect geologic and tectonic structures help loosen rock masses on slopes of present topography. Fracture zones and systems of joints and faults display different orientations along slopes and ridges. Failure planes in jointed rocks mainly depend on the attitude, spacing, and number of sets of joints present in the rock. Hence, due to intense fracturing and shearing of rocks landslides are induced.

Instability in the form of slumps, rockslides, rock falls, gully erosion, creep, and subsidence has been recognized in this area. These landslides of varying magnitudes commonly occur during heavy rains, thereby causing blockage of a very strategic road that connects the states of Nagaland and Manipur (Anand, 1988).

The slides in this area too have been caused due to diverse factors. Some of the landslides in this area have occurred at the sites of ancient landslides which have been reactivated. The areas of abundant recent landslides often coincide with areas of abundant ancient landslide deposits and that accurate mapping of these ancient deposits in conjunction with other factors such as slope angles and bedrock geology can yield significant data for regional analyses of slope stability (Nilsen et al, 1976). The evaluation should include an analysis of the slope stability characteristics of the terrain, incorporating factors such as degree of slope, bedrock, and soil characteristics, seismic triggering of landslides, and other factors (Brabb et al, 1972; Nilsen and Brabb, 1972).

Landslides can result in enormous casualties and huge economic losses in mountainous regions. In order to mitigate landslide hazard effectively, new methodologies are required to develop a better understanding of landslide hazard and to make rational decisions on the allocation of funds for management of landslide risk.
weights for all classes of the factor maps. On the basis of these weights, the relevant maps were selected for the combination into landslide susceptibility maps. Two individual GIS layers geomorphological main units and subunits are used in this method. On the basis of the geomorphological maps a landslide susceptibility map was made using a direct mapping approach.

### 3.2.1 Influence of Geomorphometry

The evaluation of the natural environmental condition is important in landslide assessment. The conditions from which landslide are activated can be determined by the current landforms and its descriptions.

Landslides constitute a geomorphic process influenced by morphometric features such as slope, drainage, etc. Landslides can be caused by many processes and characteristics including geological, morphological, physical (including rainfall and snowmelt), and human (Cruden and Varnes, 1996). Spatial variations in exceedance probabilities imply that the occurrence of landslides is at least partly a function of varying physical characteristics of hillslopes. Two of the most important physical characteristics of hillslopes are slope and geology (Galster and Laprade, 1991). The basic conditions for slide initiation are determined by a complex interaction of environmental factors such as geological, geomorphologic, hydrometeorological, and hydrogeological. The most important factor amongst these is the geomorphologic condition, that is, the degree of relief (Matula, 1969). Low values of relief indicate that the area has undergone very little differential erosion whereas high values may indicate the presence of longitudinal or transverse faults passing through an area.

### 3.3 RAINFALL

High rainfall may affect natural slopes differently than slopes that have been extensively cut and filled, deforested, or burnt. Areas with high mean annual rainfall are generally associated with abundant recent landslides. Extreme rainfall often triggers landslides, sometimes with a considerable delay, pointing to a decrease in the
shearing strength of the soil due to swelling (Veder and Hilbert, 1980). Rainfall of high intensity generally leads to increased landslide activity. The amount, type, and yearly distribution of precipitation also affect other factors that control landslides such as vegetation, soils, and steepness of slopes. In addition to the annual rainfall, the recurrence interval of major storms, the yearly pattern of rainfall and longer-term changes in rainfall must be considered. Higher rainfall intensity is probably required to generate landslides during the early months of the rainy seasons than the later months. Landsliding apparently occurs more easily when the ground is saturated or has been previously wetted and the groundwater table is high. The sequence of wet and dry spells during the rainy season is another important factor affecting landslide activity. The dry period probably reduces the effects of the previous precipitation on the landslide-generating capabilities of succeeding storms (Nilsen and Turner, 1975). They carried out a study on influence of rainfall and ancient landslide deposits on recent landslides in urban areas of Contra Costa County, California. The record of landslides that caused damage to manmade structures in Contra County during the 1950-71 period indicates that most of them have been in urbanized hillside areas along the west edge of the county. They have occurred primarily in areas where ancient landslide deposits are abundant. This relationship suggests that the ancient landslide deposits are commonly reactivated by the addition of water to and by cutting and filling of these slopes. The history of landslide activity also indicates that the distribution, amount and pattern of rainfall exert a strong influence on landsliding. In general, more rainfall is required at the beginning of the rainy season than at the end to produce large numbers of landslides. The pattern of rainfall during the rainy season is more important than the total amount, so that periods of relatively continuous rainfall produce more landsliding than discrete storms that are separated by dry periods and during which ground moisture content decreases as a result of evapotranspiration.

Rainfall is one of the most popular triggers of slope instability. The mechanism by which rainstorms can lead to slope instability in the unsaturated zone in weathered igneous rock profiles include rainfall infiltration, percolation in the unsaturated part of a slope, and saturated groundwater flow resulting in the rise in groundwater tables.
Brand (1981) briefly explained the mechanism of rain induced failure in unsaturated residual soil. Zaruba and Mencle (1982) studied the relationship between the amount of rainfall and frequency of landslide events and also established that increase in number of landslides coincide with the period of increased rainfall. Bhandari (1987) reported that the degrees of severity of Himalayan landslides are increasing due to heavy or prolonged rainfalls or earthquakes or both. It was reported that the majority of the landslides occurred when daily rainfall was higher than 200 mm. Cascini and Versace (1988) developed mathematical models to relate historical rainfall series with slide mobilization. Jworchan and Nutralaya (1994) state that the addition of water on the slope by rainfall is the single most important process which decreases the strength, increases the stress and triggers widespread landslides. Bhasin et al. in 2002 carried out investigations on recent landslides in Gangtok, with emphasis on the triggering mechanisms that have contributed to the release and creep of natural slopes in the region. It is believed that the intense rainfall in the region not only contributes to rapid erosion and weathering of the rock mass but also increases the groundwater level that leads to reduction in the stability of natural slopes.

Baum et al. (1997) has carried out some case studies on Landslides Triggered by the Winter Storms in the Puget Lowland, Washington. Snowmelt and rainfall events triggered many landslides and debris flows in the Seattle, Washington. Although shallow slides and debris flows were the most common slope failures, many deep-seated slides also occurred. Landslide hazards in Washington State due to storm carried out by Harp et al. (1997) have shown the Factors affecting landslide distribution such as rainfall patterns, susceptibility of geologic materials and susceptibility affected by vegetative cover.

Every year monsoon rains bring down thousands of landslides upon the highways of the Himalayan region. Storms coming after prolonged rainfall generate more landslides than storms that occur at the beginning of the rainy season. Thus, landslides are more frequent when the ground is saturated. Rain and melt water penetrate joints and produce hydrostatic stress in rocks. Rain increases pore water pressure in soil and consequently, decreases shear resistance. The majority of landslide incidences in India
fall in the category of rainfall-induced landslides, especially in areas subject to limited periods of intense monsoon but that remain dry during the rest of the year (CRRI, 2000a). The mechanism by which rainstorms can lead to slope instability in the unsaturated zone in weathered rock profiles include percolation into the unsaturated part of a slope resulting in rise of the groundwater tables (Zhang et al., 2000). Iverson (2002) discussed the landslide triggered by rain infiltration that operate on disparate timescales and studied the relationships between these timescales using mathematical model that uses reduced forms of Richards equation to evaluate effects of rainfall infiltration on landslide occurrence, timing, depth, and acceleration in diverse situations.

3.3.1 Correlation between Landslides and Precipitation Levels

Pichler (1957), Barata (1969), Endo (1970), Vargas (1971), Nilsen et al. (1976) and Guidicini and Iwasa (1977) have attempted correlation between landslides and precipitation levels. During periods of very intense rainfall, abundant landslides generally occur, although the time sequence and amount of the annual rainfall vary greatly at any particular place. The effect of these factors complicates the relation between rainfall and land sliding. The largest number of landslides will occur during and after long periods of relatively continuous rainfall (Nilsen and Turner, 1975). Debris accumulation on slopes is usually excessive. Abundance of water during the monsoon combines with it to cause debris flows.

3.3.2 Quasi-Dynamic Wetness Index

A model for the prediction of both topographic and climatic control on rainfall-triggered shallow landslide using a quasi-dynamic wetness index in hilly mountainous terrain was carried out by Marco et al. (2002). The model uses a 'quasi-dynamic' wetness index to predict the spatial distribution of soil saturation in response to rainfall of specified duration. The rainfall predicted to cause instability in each topographic element is characterised by duration and frequency of occurrence.
3.4 SLOPE INSTABILITY

Slope instability process are the product of Geomorphological, geological and hydrological conditions, the modification of these conditions induced by geodynamic processes and human activities, the vegetation and land use practices and the frequency and intensity of precipitation and seismicity (Soeters and Westen, 1996). Slope instability hazard assessment is based on the analysis of the terrain conditions at sites where slope failures occurred in the past (Westen, 1993).

Slope studies comprise an essential feature of geomorphic investigation. The most important control factors of slope characteristics include lithology, structure, and drainage. Diverse combinations of these factors give rise to a variety of slopes marked by favourable and unfavourable terrain conditions (Shah and Jadhav, 1987). The probability of slope instability is dependent on complex interactions among a large number of factors encompassing geotechnical, geological, hydrological, and climatic conditions, besides the influence of human activities (CRRI, 2000b). Slope morphometry includes the study of the surficial features such as slope angles with respect to the horizontal, and the relative relief of the area. Eighty one percent of landslides events have occurred on slopes that are greater than 30°. Terzaghi (1950) states that debris flows can occur on slopes greater than 30°. This is a lower limit that is somewhat shallower than for slopes on which debris slides are generated. The slope of an area is a combination of highly irregular surfaces that cannot be described by a simple mathematical equation (Sharma et al, 1996). It is opined that landslide incidences are closely associated with the inclination of slope (Fujita et al, 1976; Fujita, 1980). The safety factor for a slope is the ratio of the sum of resisting forces that act to prevent failure to the sum of the driving forces that tend to cause failure (Piteau and Peckover, 1989). This concept indicates that slope stability will depend on the forces that tend to resist failure compared with those that tend to cause failure. Every slope has shearing stresses which increase with the inclination and the height of the slope surfaces. When shearing stresses exceed the shearing strength of the material, failure occurs. Chenniah et al (1994), Abdullah and Ali (1994) studied the stability of unsaturated residual soil slope and derived the safety factor equation.
considering both positive and negative pore water pressure. Mahajan et al., (2001) studied the slope failure of Dharashala area and stated that geology, loose soil, hydrology and human are the main causes of failure. Parkash et al., (2002) demonstrated the inventory of slope failure by taking geology, geomorphology and anthropogenic activity.

According to Emelyanova (1977) the lithology and structure play a vital role in the development and disposition of slopes and instability pattern in any area. The degree of fracturing and shearing, and attitude of beds or joints in relation to slope geometry are important criteria in determining slope stability conditions. There is a delicate balance of different factors for slope stability. Any natural disturbance or human activity that affects the balance is bound to destabilise slopes (Mehrotra et al, 1993).

Under normal conditions, hill-slope systems adjust to fluctuations in relief energy by soil creep, perhaps due to cyclical undercutting caused by streams and surficial erosion, often abetted by biogenic processes. Sometimes, however, due to rate of change, the hill-slope system is forced to store excess relief energy and becomes over-steepened and becomes vulnerable to disturbances such as heavy rainfall, vibration, and biogenic impact like forest fire or human construction in its environment. The slope then fails, moving abruptly to a new morphological state, often of greater stability (Haigh, 1988). According to Thigale et al (1998) slope metamorphosis due to anthropogenic changes is most conducive in the mechanism of landslides. The failure of natural slopes clears the surface of vegetation and other soil cover thereby exposing the surface to further erosion by surface and subsurface waters (Choubey and Lallenmawia, 1987).

A landslide will develop at the toe of a slope as soon as the driving forces exceed the resisting forces with average shear strength (Veder and Hilbert, 1980). Excessive load on the head of slopes are known to cause landslides. This is usually attributed to high pore-water pressure and large slope deformations (CRRI, 2000a). Inherent geological characteristics of the strata and geometry of the slopes control the stability of slopes and, in turn, landslides. Active tectonic movement has result in weaknesses across
certain tectonic zones that are prone to extensive landslides and other types of mass movement. Deforestation as a result of felling trees for timber, animal fodder and removal of vegetation cover because of developmental activities are also responsible for the increase rate of soil erosion and destabilization of slopes prone to landslides. (Naithani, A. K., 1999)

3.5 GEOINFORMATICS IN LANDSLIDE STUDIES

The Earth observation satellites provide comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals and thus have become valuable for continuous monitoring of surface parameters related to natural disasters (Rao D.P., 2000). Remotely sensed data products provide most authentic and accurate information on earth’s surface features and processes involved. In the recent past, there have been various attempts demonstrating application of satellite data products in landslide mapping and hazard zonation by Varnes (1984), Nabil (1989), Mckean et al. (1991), Westen et al. (1996), and Montovani et al. (1996). In most of the studies, remotely sensed data products have been used for mapping of landslide and extraction of information on various geoenvironmental parameters such as lithology, structure, land use, drainage, road excavations and vegetation cover, which directly or indirectly influence slope stability of a region.

Kusaka et al., (1996) used the LANDSAT thermal bands to identify areas of perennially wet soil, which were linked with potential landslides. Satellite imageries have been used in the analysis of landslide occurrence primarily through the analysis of colour composites. Several studies have experimented with the use of true colour composite (Trench and Sauchyn 1978; Greenbaum et al., 1996). In most cases the primary restriction has proven to be spatial resolution, with only landslides of approx. 50 m x 50 m or larger being easily resolved. Rather better results were achieved using the 5.8 m spatial resolution of the IRS-I instrument (Nagarajan et al. 1998). False colour composite (FCC) images have proven useful in some cases, especially where a landslide scar provides a clear change in the surface properties, such as the removal of forest to expose bare soil. Greenbaum et al. (1996) successfully used this technique.
for the examination of landslides in Papua New Guinea. Similar results were also achieved by Rothery (1987) to identify rock avalanche deposits. Kuo Yu-Chuan et al (2000) carried out studies on identification of landslides induced by the Chi-Chi Earthquake using Spot multispectral images in Taiwan. In this study they demonstrated that the anisotropic spatial modeling approach of image-to-image registration yields high registration accuracy in mountainous and rugged terrain areas. The multi-temporal differencing technique yields a difference image using two (IR/R) images, and a threshold grey-level is determined for successful change detection.

3.5.1 Stereo Imaging Capabilities in Landslide Studies

Aerial photographs and large-scale satellite images have been used to locate areas with landslide incidence. Higher spatial resolution and stereo imaging capability of IRS -IC and 1D enable further refining of the location and monitoring of landslides. A number of studies have been carried out using satellite data and aerial photographs to develop appropriate methodologies for terrain classification and preparation of maps showing landslide hazards. Developments in space-based earth observation and weather watch capabilities in future may help refining existing models/approaches for prediction of such events and their management (Rao D.P., 2000). Westen et al., 1993, demonstrate the use of large scale stereoscopic imagery detection of individual elements of landslide.

3.5.2 Evaluation of Landslide Hazard

Among the various natural hazards, landslides are the most widespread and damaging hazard. They cause loss of life and property, damage to natural resources (vegetation, land and soil) and hamper developmental projects like roads, bridges and communication lines, etc. The evaluation of landslide hazard is a complex task as the occurrence of landslides is dependent on many factors. The high susceptibility to landslides of the Himalayan terrain is mainly due to a complex geological setting combined with contemporary crustal movements, varying slopes and relief, heavy rainfall, along with ever-increasing human interference in the ecosystem (Naithani
A.K., 1999). Recent research has demonstrated that in mountain chains undergoing high rates of uplift, landslides are an inevitable and essential environmental process (Petley and Reid, 1999).

Kumar S. et al., (2002) have discussed the analysis of the earthquake and rainfall induced slope failures in GIS and formulates the possible framework. They have demonstrated the ability of the GIS to incorporate the spatially varying data of ground elevation, soil properties, etc. in the engineering analysis of the slope stability. Nagarajan et al., (1998) has attempted the study to calculated the probability of occurrence of mass movement based on the various terrain parameters and their cumulative influence (weightage-derived from ground-based information), and knowledge-based classification and integration of terrain attributes using GIS would help in the demarcation of areas prone to slides under a given rainfall. DEM was used to portray the areas susceptible to similar slides. Interpolated elevation data was also used to generate a slope map by specifying various slope ranges. Westen (1993) demonstrated two examples of the application of remote sensing and geographic information systems for geological hazard mitigation, one in determining flood hazard in Bangladesh, and the other one on determining landslide hazard in the Andes and discusses the various scale related analysis. Ajalleian et al., (2000) has investigated the role of land use change and its relation to landslide in southwest of Isfahan in central, Iran using GIS. It is concluded that the most important landslide points has occurred in the areas which changed the land use and most landslides have occurred around the roads that point to the effect of civil activities like road, building etc. They prepared different theme maps such as rain-rate map, slope map, hypsometry map and aspect map.

3.5.2.1 Evaluation of Landslide Hazard Using Different Models in GIS

In the recent past various techniques and methods have been proposed to analyse factors and produce maps portraying the probability of occurrence of landslide phenomena in future. Hansen (1984) discussed two principal method of landslide hazard mapping, namely direct and indirect mapping.
The direct method consists of geomorphic mapping according to which a zonation is made of those sites where failures are most likely to occur. The indirect method includes two different approaches, namely the heuristic (knowledge driven) and statistical (data driven) techniques (Carrara et al., 1995) and demonstrate landslide hazard mapping in the Tescio and Carpina basins using these model. In the heuristic approach, landslide influencing factors are ranked and weights are assigned according to their assumed or expected importance in causing mass movements. In the statistical approach, the role of each factor is determined based on the relationship with the past/present landslide distribution. With the advancement of computing technology, it has become easier to apply various statistical methods to analyse landslide phenomena and derive zonation maps. This is facilitated due to the fact that information from remotely sensed data can be digitally processed and integrated with other ancillary information using GIS, which provide efficient tools for collecting, storing, retrieving, transforming, manipulating, and displaying spatially distributed data. As a result, there has been tremendous progress in the field of geological data integration using GIS and various attempts have been made on spatial prediction of landslide using statistical models (Westen, 1993; Chung et al., 1995; Yin and Yan, 1988). Wadge et al., (1993) discuss the modeling approach of Empirical or Inductive and Deterministic or Deductive and shown a case example of landslide hazard assessment using these models in Western Cyprus. Beguería et al., (2003) contributed a comparison between statistical and deterministic models for shallow landslides and debris flows.

Terlien et al., (1995) demonstrated landslide hazard assessment using deterministic modelling in Gis-Based in Costa Rica and Colombia. Zézere et al., (2003) generated a methodology for the probabilistic evaluation of landslide hazard, taking in account both the landslide susceptibility and the instability triggering factors. Susceptibility is evaluated using algorithms based on statistical/probabilistic analysis (Bayesian model) over unique-condition terrain units on a raster basis. The landslide susceptibility map is prepared by sorting all pixels according to the pixel susceptibility value in descending order.

The relationships between the casual factors and the occurrences of the landslides and that the spatial data representing the causal factors contained in the GIS database can be used to formulate the future landslide hazard (Chung et al., 2002). Mechanical models have also been used to estimate failure probability based on uncertainties about infiltration of rainfall, or pore pressure, and soil strength (Wu, et al., 2000). The simplest method merely involves overlaying of land cover before and after a landslide triggering event such as a hurricane, and looking for the differences between the maps (Lin, et al., 1999). Such a method will not predict future landslides effectively as it does not use any attributes in an area where landslides have not already occurred as examples.

Most methods compare a variety of parameters but focus on one or two main attributes deemed to have the most significant effect on landslide occurrence in the area being studied, such as the ‘dip-slope’ model presented by Liu, J.K. (1985) which notes high susceptibility to landslides on slopes with stratigraphic dips parallel or sub-parallel to the slope angle. Sarkar and Kanungo (2002) take the opposite approach to statistically analyze lineaments, roads, and drainages for their proximity to existing landslides but makes no mention of the effects of rock type, dip, climate, etc. In this case it was found that there was a strong correlation of landslides to roads, where the roads have cut into slopes introducing instabilities.

Watts et al., (2003) carried out case studies on landslide tsunami using a Boussinesq model and a fully nonlinear tsunami generation model. Their strategy is based on the traditional view of tsunamis involving three steps: generation, propagation, and inundation for Submarine Mass Failures (SMF), or underwater landslides. They also demonstrate a hydrodynamic modeling strategy for SMF tsunamis. Jibson et al., (1998) developed a method for producing digital probabilistic seismic landslide
hazard maps in Los Angeles, California, area using dynamic model based on Newmark permanent-deformation analysis by combining data sets of topography, geology, shear strength, and seismic shaking of an area and shows yields estimates of coseismic landslide displacement in each grid cell from the earthquake.

GIS is very suitable for indirect landslide susceptibility mapping, in which all possible landslide contributing terrain factors are combined with a landslide inventory map, using data-integration techniques (Bonham-Carter, 1994; Chung et al., 1995).

Corominas J. et al., (2003) has attempted integrated studies on landslide susceptibility analysis and hazard assessment in Andorra, by taking the location of the potential slope failures, and estimation of both landslide volume and runout distance. In the susceptible areas, landslide of landslide runout, magnitude and frequency has been determined in order to produce the hazard zoning map.

Yuan and Mohd, (1997) show that remote sensing techniques, when integrated with GIS can provide a useful tool to study potential landslide areas. However, the accuracy of the final result depends on the parameters that are included in the data set. The integration of GIS with remote sensing data and thematic map data may facilitate greatly the assessment and estimation of regional landslide hazards.


Various integration techniques and models are discussed by Bhan and Champati Ray (1998) and stated that the techniques are best suited to work with a spatial database consisting of information derived from ancillary sources and remotely sensed data products. The main purpose of various data integration techniques is to combine spatial data from diverse sources together to describe and analyse interactions, to
make predictions with models, and to provide support to decision-makers. Although many of these models were not originally developed for landslide hazard zonation, the underlying principle is similar in many respects. Hence, some of the statistical models/techniques can be used as a methodology or can be integrated in a methodology for landslide hazard zonation. While considering data integration techniques for landslide hazard zonation two important assumption is made: occurrences of past landslide included in the area are dependent on the input of spatial geoscientific data, and the future will occur under similar conditions in which the past landslide have occurred. Two categories of data integration techniques involves, the first category including more well known methods of multivariate techniques such as regression analysis and discriminant function and the second category based on favourability function that includes probability measures, Dempster-Shafer belief function, certainty factors and fuzzy membership function (Chung and Fabbri, 1993).

Several field-based hazard zonation studies with manual integration of data have been carried out in the Himalayas (Pachauri and Pant 1992, Gupta et al., 1993, Virdi et al., 1997). However, these approaches have several drawbacks, such as the extent of the area covered is generally small and manual overlay of thematic maps is tedious and has poor integration capability. The use of aerial photographs has removed some of these problems to some extent. With the advent of remote sensing and GIS technology, it has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geology, structure, surface cover, slope characteristics, etc. of an area which can be used for landslide hazard zonation (Westen 1994, Gupta and Joshi 1990, Gupta 1991, Sabins 1986).

3.5.3 GIS in Landslide Prediction Models

Prediction of potential landslide areas have been very difficult because of the complexity of the factors involved and the relationship to each other which is wide ranging. The state of the art techniques in landslide prediction is in the use of genetic computing with GIS. These systems are trained by letting the algorithms create random selection parameters and parameter weightings, and comparing predicted
landslides with inventories of existing landslides in a known area. The best algorithms are kept and bred together to produce new variations that can again be tested. Advances in the understanding of the dynamics of landslide motions through real-time monitoring of active mass movements will no doubt lead to refinements in GIS predictions in the future (Reid, E., and LaHusen, R., 1998). Chung and Fabbri (1993, 1999) developed statistical procedures of predictive modelling, applying favourability functions on individual parameters. Using these statistical methods, terrain units or grid cells are transformed to new values representing the degree of probability, certainty, belief or plausibility that the respective terrain units or grid cells may contain or can be expected to be subject to a particular landslide in the future. Aldridge (1999) developed a methodology for Rough Set Based Geographic Knowledge Discovery in Database and stated that this approach to model development seems to be particularly suited to processing digital map data that includes nominal scale measures.

Nakamura, H. et al., (2001) developed three-dimensional movement simulation model base on fluid theory to predict the extension of landslide. Chi Kwang-Hoon et al., (2002) carried out landslide stability analysis and prediction modeling using DEM-based hydrological features such as flow-direction, flow-accumulation, flowlength, wetness index and based on likelihood ratio model for landslide prediction and stated that space-robustness of landslide prediction models in conjunction with DEM-based landslide stability analysis can be effectively utilized to search out unrevealed or hidden landslide occurrences.

One of the biggest potential problems with landslide prediction is the inconsistencies found in landslides mapped by different geologists (Ardizzone et al., 2002). Perhaps a consistent definition of landslide disturbance given to the geologists ahead of time would reduce this problem. There are two main methods that can be used to validate the predictive models. They both divide the data of the study area into two groups, spatially or temporally, into a training group and a test group. The model is based on the training area or time-space and then tested on the remainder of the data to calculate accuracy for the predictions (Fabbri and Chung, 2001).
The French method of hazard mapping called ZERMOS has included factors like lithology, structure, slope morphology, and hydrology where the mapped area is divided into four zones of different levels of hazards with types of movement and direction, activity, and sites of erosion that are noted using different symbols. Varnes (1980) prepared a landslide zonation map using slope, soil thickness, land use practice, and drainage as the basic factors. Takie (1982) described methods for making debris flow hazard maps taking into account the type of rock fracturing, weathering characteristics, springs, vegetative cover, valley slopes, etc. Kawakami and Saito (1984) used valley density, elevation, slope angle, and formations for preparing a quantified landslide risk map. Brabb (1984) provided a useful review of development of landslide hazard mapping. Wagner et al. (1987) discussed preparation of rock and debris slide risk maps for road alignment purposes using geological, structural, slope, and geomorphologic factors.

Several workers in India too have attempted LHZ mapping considering various factors of the terrain. Seshagiri and Badrinarayan (1982) carried out the zonation of the Nilgiri hills considering slope, land use, soil cover and drainage using numerical ratings of these factors depending on frequency of landslides present. Hazard zonation studies were taken up during 1984 at four locations in the North and East Sikkim (CRRI, 1989). The overall stability of the slope was assessed quantitatively on the basis of the nature and characteristics of the rock and soil materials constituting the slope formation, the slope angle, condition of the slope surface, hydrological features, and toe erosion. In this study, the overall rating of the slope stability was divided into three categories, viz., very good, good, and fair. Choubey and Litoria (1990) carried out LHZ mapping of the Garhwal Himalayas considering slope, lithology, structure, and earthquake epicentres. Mehrotra et al., (1992) attempted an empirical approach for LHZ mapping based on a Landslide Susceptibility Index (LSI) using factors like lithology, slope angle, distance from major thrusts and faults, land use pattern, and drainage density in relation to frequency of existing landslides. Anbalagan (1992) carried out landslide hazard zonation of the Kathgodam-Nainital area in the Kumaon Himalayas based on slope, lithology, structure, relative relief, land use and land cover, and groundwater conditions and proposed the Landslide
Schuster and Highland, (2001) show that in spite of improvements in recognition, prediction, mitigative measures, and warning systems, economic losses and casualties due to landslides in the western hemisphere appear to be growing as a result of increasing development of landslide-prone areas due to population pressures. Environmental disturbances are the results of the general tendency toward degradation of the earth's surface by gravitational mass wasting and erosion.

3.6 LANDSLIDE HAZARD ZONATION

Landslide Hazard Zonation by cartographic methods has been carried out by several workers since the sixties. Though hazard is a process, it is very difficult to map a process which has not yet occurred. However, hazard mapping may be defined as "the identification of those sites where there is a likelihood of hazardous events rather than hazard affected sites" (Varnes, 1984). If the required information on terrain characteristics is available, the slope surface can be divided into different classes related to stability. Preparation of comprehensive landslide hazard zonation map requires intensive and sustained efforts. Blanc and Cleveland (1968) prepared landslide hazard zonation maps of Southern California in which geological formations were divided into different lithologic groups and combined with slope categories, below and above the critical angle. Nilsen and Brabb (1973) used maps showing geological formations, slope ranges, and landslide debris to prepare a landslide zonation map of San Francisco Bay region. Brabb et al., (1972) have rated the slope stability of geological units in San Mateo County, California on the basis of percentage of outcrop area of a formation occupied by landslide debris, combined with slope classes. Radbruch and Crowther (1973), in California, classified the area on the basis of lithology and the number of landslides present. In the United States, Radbruch et al., (1976) considered the frequency of slope failure in different groups of geologic units. A similar grouping of lithology and mass movements was used by Rodriguez et al., (1978) in southern Spain.
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Hazard Evaluation Factor (HEF) rating scheme for preparation of LHZ maps. This method is suitable for zonation mapping of mountainous terrain. The method involves demarcation of facets, preparation of thematic maps, estimation of HEF rating, calculation of Total Estimated Hazard (TEHD), and Hazard Zonation of the area. Majumdar (1990) prepared a zonation map for northeastern part of India by considering the parameters like geological set up of the area, degree of relief and intensity of precipitation. Thigale et al., (1996) prepared landslide hazard zonation database of part of the Western Ghats, by taking different factors like slope inclination, dissection index, relative relief, rainfall distribution, geohydrology, anthropogenic changes and seismicity. LHZ maps are used to evaluate landslide susceptible zones (Sharan, 1995). Thigale et al., (1998) opine that the difficulty in preparing hazard zonation maps is due to the paucity of data on topography, climate, geology, hydrogeology, seismicity, and anthropogenic changes, and their components or variables.

Saha et al., (2002) carried out GIS-based Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas by taking various data layers considered are land use/land cover, buffer map of thrusts, buffer map of photolineaments, lithology, buffer map of drainage, slope angle and relative relief and showed that GIS-based methodology for integration of various datasets seems to be quite suitable for developing a landslide hazard zonation map. A similar type of study has been carried out by Gupta and Joshi (1990) in the Himalayas using a GIS approach where an index value has been given to factors like land use, lithology, major tectonic features, and azimuth of landslides. Panigrahi et al., (2002) discussed the uses of remote sensing in GIS environment for preparation of landslide hazard zonation. Ramakrishnan et al., (2002) carrying out landslide zonation for hill area development in the Nilgiri District showed that most of the landslides occur due to exhaustive deforestation for the development of urbanization and plantation. In these areas rainwater directly penetrates into the soil and cause landslides. High intensity rainfall triggered most of the landslides in the Nilgiri District.