CHAPTER II

LITERATURE REVIEW

2.1. General

This chapter elucidates the surveyed literature on the assessment of landslide studies. From this, the methodology is derived and also used for the preparation of various thematic maps. Analytical procedure is brought from this literature. Apart from this, literature also highlighted as and when discussed in other chapters. The literature highlights the methods used to assess the types of landslide hazards and previous landslide studies in India and around the world. Landslide related literature were collected and arranged in three stages; existing landslides and analysis and forecast of the slope failures in space (spatial distribution) and time (temporal distribution). In general, the landslide analysis using remote sensing and GIS application and preparation of thematic maps are reviewed in this chapter.

2.2. Landslides - General

Jagannatha Rao (1989) has described the methods of investigation. Landslide investigation broadly comprises field and laboratory analyses. Both geological and geotechnical aspects, in the broad sense of the terms need to be studied. According to Zillman (1999), landslides are predicted as the third type of natural disaster in terms of worldwide prominence. Landslides causes multiple human and economic losses due to natural conditions or anthropogenic activities (Fleming, 1980; Guzzetti, 1999). More widespread Slope failures over the years may cause more damage to the properties than
any other geological hazards (Varnes, 1984).

More than 10 million people were affected and 57,028 deaths have caused due to landslides around the world from April 1903 to till January 2007 with a damage of US $5 billion (INTERNATIONAL DEVELOPMENT OFFICE OF FOREIGN DISASTER ASSISTANCE/CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS (CRED) (2007) Annual Disaster Statistical Review, The Numbers and Trends, pp.1-47).

The worldwide attention is increased mainly due to increasing awareness of the socio-economic impact of landslides, as well as the increasing pressure of urbanization on the mountain environment (Aleotti and Chowdhury, 1999). Varnes (1984) in his studies explained about the prediction of landslide event in space and time and also he has highlighted where this will happened in the mountain terrain along with ranking. He has also given the Landslide Hazard Zonation (LHZ) or Landslide Susceptibility Zonation (LSZ) mapping methods in his studies.

Catastrophic nature of landslide studies were carried out by many researchers (Brabb and Harrod 1989; Brabb 1993). Annual losses in United States, Japan, India and Italy at one billion or more each was estimated by Schuster and Fleming, (1986). Schuster and Highland (2001) in their studies highlights the socio-economic impact of landslides in Western Hemisphere events such as a debris avalanche in 1970 in Huascaran, Peru with a death toll of 20,000 people, a debris flow in 1985 in Nevada del Ruiz.

Landslide data bases vary statistically given by different scientific
organizations. This in turn reflects varying loss quantity of economic or human loss, due to the following causes: Frequency is more, Vary from event to event, Recurrence of landslides and most landslide disasters are not recorded. Record of landslide impacts (historic events) are not perfectly recorded. The records of other countries under similar natural conditions show larger variations even though the intensity is same. The registration of landslides in mountainous areas with low risk but high hazard is cumbersome as not many people are affected. All the above said information make an importance of landslide study and opened up eyes on me to look at from Disaster perspectives. The general literature cited above helps in understanding of landslides and in particular Nilgiri regions of the study area.

2.3. Rainfall, Water level and Landslides

Landslides triggering factors are voluminous. Rainfall is one such factor. The soil nature in the hilly terrain is highly altered by human intervention resulting in the landslides due to rainfall. Since 1978, Nilgiri is prone to series of landslides. The landslide frequency has increased in recent years. In the recent and past, landslide occurrence due to rainfall is recorded in the years 1993, 1995, 2002, 2007 and 2009.

The pore pressure upsurge has triggered the landslide occurrence during rainy season in Nilgiri (Ramasamy et al. 2006a). Deforestation also induces landslides to a certain extent in Nilgiris. A loss of 25.6% of forest land in the southern part has been recorded in between 1973 and 1995 (Jha et al. 2000). The decrease of shoals in the area has been noted to a large scale i.e. from 8600 ha to
4225 ha in between 1849 and 1992.

The rainfall data assessment is highly helpful in identifying the landslide studies. Intensity and duration of rainfall also activate landslides (Jaganatha Rao, 1989).

Statistical analysis on rainfall for sorting the data sets into season wise and arriving mean is highly helpful to study graphically (Suresh, 2009).

Spatial mapping using GIS for rainfall studies is highly helpful in any studies related to geosciences is noteworthy (Gurugnanam et al. 2010).

Groundwater is one of the important factors, which cause landslides. Groundwater conditions is represented in the form of depth to water level. Groundwater conditions of the area depend on geological and hydrogeological parameters, its storage on the aquifer characteristics and its recharge on the rate and duration of precipitation, lithological characters of the area, gradient of the slope etc. (Venkat Reddy, 2010). Depth to water level, is the other dominant factor influencing the landslides (Arunkumar, 2015). The water level and flow of this infiltrated water along with the slope of the terrain plays a major role in assessing the landslides (Gurugnanam, 2012).

Statistical data on interpreting the water level (Pankaj, 2011) and spatial mapping of the above in GIS also helpful in predicting the landslide possible zones. The literature cited above helps in understanding the importance of rainfall and water level data and interpretation techniques along with spatial mapping techniques in GIS.
2.4. Other Thematic maps and landslides

Study of geological parameters is an important one for landslide studies. The geology of the region is studied to understand its rock formation, petrogenesis and geomorphological factors that are affected by the existing lithological formations. Rocks and soils are the important factors which influence the movement of rocks (Venkat Reddy, 2010). The detailed lithological mapping is very important one in characterizing the landslides. GIS based spatial mapping gives an idea of the distribution of the litho units and to predict logically its characteristics. This has helped in understating the litho-unit importance of sliding and mapping them in the field.

Soil is the important accountable parameter in landslide studies. The study of soil type, soil color and soil depth in all the districts of India are done by Soil Survey and Land Use Organization (SSI, 1998). Debris flow is characterized by slow movement in which a combination of loose soil, rock, organic matter, air and water mobilizes as slurry that flows down slope (Duggal et al. 2014). Debris fall are used when the material involved in failure is essentially unconsolidated in nature (Parbin Singh, 2008). The intensity of landslides varies with the type of soil and thickness of soil. The sliding characteristics will vary from the internal characteristics of the soil, like porosity and permeability. All these parameters were considered for mapping of soil in the study area, during field validation and also assigning due weightages in AHP methods for assessing landslides.

Slope: It has been observed that majority of the earth or rock failures are confined to slopes. This indicates the slopes are directly responsible for
landsides. As a rule, steeper the slope, greater is the instability of such a mass movement (Bangar, 2014). The most common driving force tending to destroy a slope is gravity, generally the weight of the slope material and that of superimposed loads and increase in this weight decreases the stability of the slope (Dimitri Krynine and Judd William, 1998).

Geomorphology is the study of landforms, plays an important role in understanding the process behind the landslides. The geomorphological investigation of landslides provide a framework for describing and mapping surface landslide processes and predicting future process behavior (Claque J.Jhon and Stead Doughs et al. 2012).

The investigations on land use / land cover are advanced since fifties in different parts of the world. Remote sensing methods consisting of aerial photography plays a significant role because of its application and effort in retrieval of information about the earth’s characteristics. Various studies have been conducted all over the world regarding the change analysis. They are important to develop effective management strategies for worldwide (Parker and Meretsky, 2004; Caruso et al. 2005; Bazgeera et al. 2008; Ashraf, 2013).

Investigations on land use / land cover have been done in various parts of India through aerial photographs and satellite remote sensing methodology. Air photo interpretation and analysis were worked out by Tewari (1977).

Land use practices like terracing minimizes slope gradient, breaks the original shape in to sorted units, conserves soil moisture and removes run-off in a controlled fashion (Cook and Dornkamp, 1993).
Murthy and Venkateswara Rao (1997) contributed few suggestions based on their temporal studies of land use / land cover in Varaha River basin, Andhra Pradesh, using remote sensing techniques. Over the years, remote sensing has been used for land use / land cover mapping in various parts of India (Rathore, 1996; Palaniyandi and Nagarathinam, 1997; Jaiswal et al. 1999; Minakshi et al. 1999. Bhamabhatt et al. (2000) has demarcated land use / land cover change mapping in Mahi canal command area, Gujarat, using multi-temporal satellite data that have been used to investigate the land use / land cover and change detection.

Yang and Lo (2002) prepared land use / land cover changes in the area of Atlanta using high-resolution satellite imagery.

Pal and Mather (2003) has gathered and analysed land use / land cover and soil characteristics on micro level basis through space technology and GIS. Luque (2000) has evaluated landscape and geomorphic characteristics using multi-spectral data and thematic maps in the area of New Jersey, Pine Barrens.

Jayakumar and Arockiasamy (2003) studied land use / land cover mapping and their changes in part of Eastern Ghats with special reference to remote sensing and GIS. Land use / land cover alterations and their impact assessment particularly with reference to pre-monsoon climatic conditions at Gangetic planes of West Bengal region have been studied by Sadhukhan et al. (2003).

Identification of the agricultural pattern and their impact over Hazira region, Gujarat through spatial, non-spatial and satellite techniques along with field verification has been done by Shailesh Nayak, (2005). A detailed mapping of vegetation and other land use / land cover identification in an Alpine and arid
region (Nubra Valley, Ladakh) was performed using satellite remote sensing data has been demarcated by Joshi, (2006).

Land cover change has been described as the most significant regional anthropogenic disturbance to the environment (Roberts et al. 1998). In essence both land use and land cover changes are the products of prevailing interacting natural and anthropogenic processes by human activities. Studying land use dynamics is essential in order to examine various ecological and developmental consequences of land use change over a period of hiatus. Following are the key points that lead to dedicate study on land use/land cover change. Land use and land cover change with land degradation are underlying factor elements to environmental processes, change and management through their influence on biodiversity, heat and moisture budgets, trace gas emissions, carbon cycling, livelihoods, a wide range of socio-economic and ecological processes (Desanker et al. 1997; Verburg et al. 2000; Verburg et al. 2002; Fasona and Omojola, 2005).

Application of remotely sensed data made possible to study the changes in land cover in less time, at low cost and with better accuracy (Kachhwaha, 1985) in association with Geographical Information System (GIS) that provide suitable platform for data analysis, update and retrieval (Star et al. 1997 McCracker et al. 1998 Chilar, 2000). Space borne remotely sensed data may be particularly useful in developing countries where recent and reliable spatial information is lacking (Dong et al. 1997). Remote sensing technology and geographic information system (GIS) provide efficient methods for analysis of land use issues and tools for land use planning and modeling. By understanding the driving forces of land
use development in the past, managing the current situation with modern GIS
tools and modeling the future, one is able to develop plans for multiple uses of
natural resources and nature conservation. The change in any form of land use is
largely related either with the external forces and the pressure on built-up land
within the system (Bisht and Kothyari, 2001).

The shortage of landslide inventory data in Nilgiris, the geological,
geomorphological, tectonic and hydrological conditions prevailed and triggered
the landslides in the area is very less and unknown in many cases. The aerial
photos or satellite images play a major role in the identification and study the
landslides and it scars created in the terrain.

2.5. Morphometric Analysis

Morphometric analysis using stream networks have been used to
quantitatively describe stream basins with the goal of understanding their
processes and evolution (Horton, 1945; Strahler, 1952, 1957, 1958 and 1964;
Shreve, 1967; Patton and Baker, 1976; Rodrique-Iturbe and Valdes, 1979;
Abrahams, 1984; Chutha and Doodge, 1990; Wilgoose et al. 1991). Particularly
through the use of GIS, karst- drainage network data pertaining to the three-
dimensional flow network, surface topography and catchments and discharge can
be stored, managed, and queried for analysis (Maguire and Dangermond, 1994;
Martin, 1996; Maidment and Djokic, 2000; Szukalski, 2001). This study supports
a long-range goal of understanding processes associated with evolving karst-
drainage systems and the Mammoth Cave Watershed in particular, by analysis of
cave-conduit function.
2.6. Landslide Inventory

The existing landslides in a particular area can be surveyed and landslide hazard maps can be prepared by conducting proper landslide inventory studies. The information about spatial distribution of landslides and its movement activity comprises majority in the landslide inventory map (Parise, 2002). There is no stable technique is used in landslide inventory map preparation (Yilmaz et al. 2012). A single X, Y coordinate represents the point data in GIS by Yilmaz in 2009. He also states that this does not reflect the landslide affected area and used only when the real degree of landslide of a small area cannot be plotted due to map scale. The future prediction can be done only with the past datum collected and recorded. The conditions and processes involved in triggering landslide in a particular area can be studied with the help of this landslide inventory mapping prepared from the literature collected (Yilmaz et al. 2012).

A typical method involves collection of historic records, field investigation, interviews, image interpretation and satellite imageries help in understanding the frequency of the slide, types of movement, the quantity in volumes and the total damage caused (Van Westen et al. 2006).

In the present study, the historical data were collected from Disaster management cell and Railway Department.

2.7. Remote Sensing and GIS in Landslide Studies

Remote Sensing (RS) and Geographical Information Data (GIS) are effective tools in generating spatial information (Pardeshi et al. 2013). Extracting relevant spatial information on landslide occurrence plays a major role in hazard
vulnerability assessment. The Earth Observation (EO) technique and its advancement in landslide detection, mapping, monitoring and hazard analysis is highly effective in Landslide susceptibility mapping (Tofani et al. 2013). The previous and aftermath images of a large landslide area can be easily interpreted and calculated using remote sensing data. The thematic layers obtained from the remote sensing data have to be integrated with ground truth. This enforces enormous amount of data storage systems, manipulation and analytical capabilities provided by the Geographic Information Systems (GIS).

The GIS introduction in Landslide research has enriched the databases for landslide analyzing and providing the solution (Wang and Unwin, 1992; Hansen et al. 1995; Mark and Ellen, 1995; Dikau et al. 1996; Dai and Lee, 2002). Landslide prediction can be easily done when GIS and Remote Sensing technique combines together. This provides a better accuracy in the results. With the help of high quality aerial photographs researchers are predicting the future for better management plans for landslides (Panikkar and Subramaniyan, 1997; Rowbotham and Dudycha, 1998; Clerici et al. 2002; Chau et al. 2004; Ayalew and Yamagishi, 2005; Guzzetti et al. 2005; Miller and Burnett, 2007; Galli et al. 2008; Pradhan and Lee, 2009; Yeon et al. 2010; Rotigliano et al. 2011).

As satellite data resolution increases the accuracy assessment of the data will also be flawless in landslide revealing, charting, observing and management and mitigation measures to be taken (Gomez et al. 2000; Naithani, 2007; Chand, 2008; Saraf et al. 2009; Akbar and Ha, 2011; Mondal and Maiti, 2012; Balsubramani and Kumaraswamy, 2013; Ma et al. 2013).
The usage of Digital Elevation Model (DEM) has massive importance in landslide hazard assessment. The DEM modeling provides a swift and objective based morphological parameters evaluation and developing a preliminary slope stability hazard maps (Niemann and Howes, 1991). Parameters such as slope angle, slope aspect, curvature, relief, lineaments, drainage, ridges etc. with a virtuous resolution can be easily extracted using DEM. Digital Elevation Modeling with high resolution is helpful in generating spatial information data layers linked with landslide hazards (Gao, 1993; Leroi, 1996; Rowbotham and Dudycha, 1998; Gomez et al. 2000; Nagarajan et al. 2000; Clerici et al. 2002; Coe et al. 2004; Ayalew and Yamagishi, 2005; Naithani, 2007; Chand, 2008; Saraf et al. 2009; Yeon et al. 2010; Rotigliano et al. 2011; Ma et al. 2013).

GIS is widely used in landslide hazard assessment especially for thematic data layers generation, computation of different indices, assigning weightages, data integration and Landslide Susceptibility Zonation (LSZ) map generation. Numerous LSZ methods such as ANN, Decision Tree model, Weighted Overlay, Frequency Ratio, Analytic Hierarchy Process (AHP), MCDA, information value method and physically based landslide hazard models are GIS based models to predict landslide probability (Terlien et al. 1995; Smyth and Royle, 2000; Chang and Liu, 2004; Pradhan and Lee, 2009; Saraf et al. 2009; Yeon et al. 2010; Akgun, 2011; Mondal and Maiti, 2012; Kavzoglu et al. 2013; Ma et al. 2013).

2.8. Landslide Studies in India

Landslide Hazard Zonation studies in India were initiated by the Geological Survey of India (GSI). The GSI has been involved in the site-
specific investigations of a number of landslides particularly those related to communications routes, urban settlements and River Valley projects. The pioneering investigation related to the stability of slopes for urban settlement dates back to 1896 when survey was called upon to study the stability of slopes around Nainital, an important hill resort. Prior to this, a classical documentation was carried out by the Sir T.H.Holland of the survey in 1893, of the catastrophic rock slide in Brihaiganaga valley that lead to creation of huge reservoir. This was instrumental in obviating loss of life by flooding due its partial breach that was predicted with uncanny accuracy.

Since those early days, the officers of the survey have carried out detailed evaluation of mechanism of failure of specific slide in different geo-environments and have evolved treatment measures for communications routes, natural and cut slopes, engineering projects as well as urban settlements. These studies are essential for designing safe slope cuts and for evolving treatment measures for failing slopes. Even though they do not answer the queries of environment conscious communities and for planners of developmental activities to arrive where, when and how much is the hazard in a particular domain. Though in regional hazard evaluation, all these questions may not be possible to be replied too. But the most central one is “how much hazardous” a particular domain for failure. This question has to be addressed objectively in any zonation exercise.

In most cases, landslide hazard zonation exercise assesses the relative hazard by comparing the slopes with one another, using the influencing
parameters without calculation of safety factors. The quality as well as, the utility of such maps is dependent on the scale at which these maps are prepared, because of this choice and treatment of the stability influencing parameters would be scale dependent.

For example, the first generation, small scale maps (1:1 million) could take into consideration the parameters like the general physical characteristics of the slope forming materials (lithology), the general relief and annual rainfall precipitation. The regional small scale zonation maps are the simple thematic representation of terrain evaluation and they serve the purpose of synoptic representation of areas where this natural phenomenon is prevalent. Contrary to this, the medium scale second generation maps on 1:50,000 scale would take into consideration the shear characteristics of the slope forming materials, the slope morphometry, the land use, geomechanical behavior of the discontinuity surfaces etc., as the inputs. Local networks of rainfall measurements as well as, the groundwater conditions are now available and these could be used for hazard evaluation as well as mapping.

During the last few decades, attempts at landslide hazard zonation studies have been made in different parts of the country. Since then a large number of landslides were investigated, but Landslide Hazard Zonation, as it is commonly understood today, is relatively a new concept. Different approaches to zonation have been followed by different investigators.

Krishnaswamy (1980) was perhaps the first to attempt landslide zonation at the national level. He made the three fold geomorphic division of India into
the peninsular, the Indo-Gangetic plain and the Extra-Peninsular as the basis for evaluating the relative incidence of landslides. The first attempt on regional level landslide hazard zonation studies in the North Eastern region (Mazumdar, 1980) and in the North West Himalaya (Narula et al. 1996) was made by GSI. The next major attempt on regional zonation was made in 1982 for the Nilgiris district of Tamil Nadu.

These maps were prepared taking into consideration of the lithology, general physiography, rainfall patterns, seismicity and domains of crustal adjustments. The basic approach in both these maps has been similar to the one suggested by Krohn and Slossen, (1976) in which the landslide prone or resistant bed-rock and steepness of the relief were used and the area categorized as high, moderate and low. The perusal of these maps would indicate that these maps could serve only the thematic representation of the lithological, tectonic and physiographic conditions and would be of very limited use for planning and execution of developmental activities or for mitigation purposes. As because within the very high domains demarcated in these maps, these area could again be subdivided into various vulnerability classes on larger scales when more rigorous analysis of the parameters is carried out on 1:50,000 scale. To explain this, large scale map of a window of high hazard zone of the smaller scale if reproduced.

The first attempts of the second generation landslide hazard zonation maps on 1: 50000 scale was attempted by the GSI in the Nilgiris hills, southern part of India, in which more than the overlay, the numerical
method with ratings were given for slope angles, thickness of soils, drainage and land use. Five landslide susceptibility zones were identified (GSI, 1982), it addresses soil and debris slides. Landslide Hazard Zonation maps on 1: 50000 scale have been prepared of an area aggregating about 12,000 km² in the Chenab, Sutlej, Beas and Ganga basins utilizing the overlay methods. In all these studies the remotely sensed database was also utilized for making the landslide incidence maps with representative field checking. The inputs for these included the detailed morphometry, characterization of slope forming materials, and the geomechanical behavior of the discontinuity surfaces which contain low strength sheared material, the critical angles of failure of different materials, identification of type of failure in a particular material and given natural conditions as derived from landslide incidences (Gupta, 1988; Sharan, 1992). These inputs give normalized conditions for identifying areas of different landslide potentials.

One of the early projects on zonation was carried out by Central Road Research Institute in 1984, in which hazard zonation techniques were used to choose a most suitable alignment from the possible alternative alignments on landslide affected stretches in Sikkim area. Subsequent monitoring has shown that the choices made have been proved to be successful. During 1989, a hazard zonation map was prepared for a part of kathgodam- Nainital highway. This map was prepared with the objective of enabling the department to evolve a suitable maintenance strategy to keep the hill slopes along the road free of landslide problem (Sharma, 1999).
Anbalagan (1992) has been evolved new quantitative approach based on major causative factors of slope instability. He adopted a landslide hazard evaluation factor rating scheme for Landslide Hazard Zonation.

Landslide hazard zonation studies in parts of Beas valley, Himachal Pradesh in parts of Bhagirathi valley, Garhwal in North Western Himalayas (Gupta and Joshi, 1990) are mostly confined to small area and limited number of slides. Studies along NH31A of Sikkim in Eastern Himalayas (Sengupta and Gohosh, 1996) are mostly based on the Landslide Hazard Evaluation Factors (LHEF) rating scheme, which is mainly a quantitative way to ascertain relative importance to factors for slope instability.

Ramakrishnan et al. (2002) have been made an attempt to identify landslide prone areas using photogrammetry with 3D GIS techniques. The advantage of the high resolution data helps in deriving 2m contour, which is ideal to get the elevation and slope values of the terrain.

Ramakrishnan et al. (2004) have developed the web based GIS for landslide inventory for the Nilgiri district. It includes spatio-temporal landslide database, different landslide inducing factors and landslide hazard zonation. This application was developed in ArcGIS to view the landslide information together with other data layers.

Prabu et al. (2009) have developed a new model for landslide hazard mapping through the integration of GIS, Remote Sensing and Neural networks. He compared conventional method of landslide mapping with the use of neural networks in landslide mapping.
Poudyal et al. (2010) carried out a comparative study on frequency ratio and artificial neural networks for Nepal Himalayas. Ten factors were selected to relate the occurrence of landslides. The weights of each factor were determined using the back-propagation training method. The accuracy of the landslide susceptibility maps produced by the frequency ratio and neural networks methods are 82.21% and 78.25%, respectively. Surprisingly, frequency ratio method produced more accurate results than artificial neural networks. This made the landslide susceptibility mapping easy and accurate for a set of given data.

Ganapathy et al. (2010) studied the need for and urgency of landslide risk planning for Nilgiri District, Tamil Nadu State, India. The major landslides in the past and their impact were given in his study. The paper provides information that led to the reduction of losses from landslides and increased public safety through improved understanding of landslide hazards. Developing the information, scientific understanding and capabilities were needed to issue accurate warnings, advisories, or notifications of landslide hazards.

Raj et al. (2011) studied the landslide hazard, and the effect of landslide-related factors at South Eastern part of Nilgiri District, Tamilnadu using the Relative Effect Method (REM) model, Geographic Information System (GIS) and remote sensing data were evaluated. This method determines the relative effect (RE) of each unit, such as surface geology, slope morphometry, climatic conditions, land use and land cover by calculating the ratio of the unit portion in coverage and landslide. Logarithmic function was used in this method. The advantages of the logarithmic function were in domain determination for output
data and equality for plus and minus domains of calculated RE's. The computed index for each grid for each factor was summed and grouped into five classes.

In Darjeeling Himalaya, landslides cause extensive damage to property, occasionally loss of life too. Mondal and Maiti (2012) applied and verified probability model, frequency ratio model and logistic regression model for landslide susceptibility mapping at Shiv-khola Watershed, Darjeeling, using Geographic information system (GIS). The validation results indicated the prediction accuracy was 99.22%, and Kappa Statistics is 0.894 was 70.42%.

Muthukumar (2013) performed geosystem response modelling for landslide vulnerability mapping in parts of Nilgiris, South India. A new method was attempted for Nilgiri mountains, Western Ghats, South India by assigning weightages to various geo-system parameters such as lithology, lineament, fracture density, geomorphology, slope, land cover and their sub-classes or sub variables, on the basis of their responses to landslides and integrated such weighted five geosystems to arrive finally at a landslide.

Rohan Kumar and Anbalagan (2016) prepared the landslide susceptibility mapping for using the analytical hierarchy process (AHP) in Tehri Reservoir Rim Region, Uttarakhand. The AHP method was used to acquire weights of factors and their classes respectively. Weights achieved from AHP method matched with the existing field conditions. Acceptable consistency ratio (CR) value was achieved for each AHP matrix. Weights of each factor were integrated with weighted sum technique and a landslide susceptibility index map was generated. Jenk’s natural
break classifier was used to classify LSI map into very low, low, moderate, high and very high landslide susceptible classes.

Since then, a number of landslide mapping programmes have been carried out in different parts of the country, mostly confined to small scales and with limited terms of references. These examples have been cited to explain how the utility of the landslide hazard maps goes on increasing with the scale of the maps.

The national and regional level Landslide Hazard Zonation maps which depict the thematic representation of slide prone areas based on general lithological, tectonic, climatic and physiographic conditions. This would be of limited use and for realistic mitigation efforts for larger scale maps at least on 1:10,000 scale has to be prepared.

There are vast tracks of the Nilgiris, Which are landslide prone and needs quick survey for zonation would take lot of resources for the large scale. From the small scale maps, high susceptibility areas should be identified as a first priority, and then highest hazard areas should be selected for large scale analysis. This will help to choose favorable locations for sitting development schemes such as townships, dams, roads and other development.

2.9. Landslide Studies around the World

Landslides have been occurring on the mountainous areas since time immemorial. But they have been studied, with some scientific curiosity, only since the 19th century. The need to overcome this geohazards has been felt since long. In fact the earliest records of regional landslide maps date back to 1783 when numerous huge landslides in parts of Calabria in Italy had affected many
settlements and blocked rivers and streams creating 215 lakes as a co-seismic effect of a major earthquake. Surprisingly such important geohazards, whose menacing power had been recognized since long, received the attention of specialist, towards correlation of various parameters in varied geo-environments to establish their slid ability only in the early sixties of the twentieth century, though a singular attempt of field data based landslide map on 1:5,00,000 scale was prepared by Almagia in 1910.

A few of such studies dealing with application of remote sensing and GIS technology in landslides are briefly discussed in the following paragraphs.

Carrara et al. (1999), in an interesting overview paper on the use of GIS technology for the prediction and monitoring of landslide hazards, indicated some of the negative aspects of the extensive use of GIS in the process, such as: Computer-generated results are considered to be more objective and accurate than products derived by experts in the conventional way through extensive field mapping; The use of GIS and the production of less accurate hazard maps by users that are not experts in earth sciences; The increased focus on the use of new computational techniques for landslide hazard assessment, and less interest on the collection of reliable data;

For the average earth scientist, it is difficult to keep up with the rapid developments in the field of Geo-information Science and Earth Observation. The number of new sensors and platforms, and the amount of acronyms is overwhelming. Also the change of GIS software from one version to the next, in which the methods that had been developed earlier on do no longer function,
because of changes in file structure or interface, can be frustrating to many earth scientists. Nevertheless, GIS has become an almost compulsory tool in landslide hazard and risk assessment, and it is the challenge to keep on using it as a tool, and not as an objective in itself. When using GIS, the following components of a landslide risk project can be differentiated: data collection, data entry, data management, and data modeling.

Powers et al. (1996) developed a digital method for visual comparison between two sets of multi temporal aerial photographs, of the active portion of the Slumgullion earth flow in Colorado, to determine horizontal displacement vectors from the movements of visually identifiable objects, such as trees and large rocks. Baum et al. (1998) report on the result of displacement gradients obtained through photogrammetrical work of multi-temporal aerial photos in Honolulu, Hawaii. Maas and Kersten (1997) present two practical studies on the helicopter-based use of a high-resolution digital still-video camera for digital aero-triangulation and the automatic generation of digital elevation models and ortho-photos. Test regions were an alpine village and a landslide area in Switzerland.

A clear classification and ranking methods of the slope instability factors and hazard level indicators could be qualitatively and quantitatively presented. Qualitative presentation shows a clear idea about the hazard zones in descriptive terms, whereas quantitative shows numerical probability estimations of landslide occurrence in a zone by Guzetti et al. (1999). Geomorphologic and heuristic models were categorized under qualitative analysis. Quantitative methods include
statistical methods, geotechnical methods and data driven methods. The methods mentioned above were used by many researchers, in different parts of the world to assess the landslide susceptibility. In the complex and large areas statistical estimation methods were used for susceptibility mapping (Cardinali et al. 2002). A lot of papers were dealing about the susceptibility model based on statistical studies but, the quality of the proposed model is very less or absent (Guzzetti et al. 1999; Cardinali et al. 2002; Chung and Fabbri, 2003).

The likelihood and logistic regression methods were used for landslide susceptibility assessment by Lee et al. (2001) in Yongin, Korea.

Artificial Intelligence (AI) and Geographic Information System (GIS) method of mapping was done by Lee et al. (2001) in the mapping of Landslide susceptibility in terrains of Hong Kong.

The weight of evidence method of Bayesian probability modelling was used in evaluating landslide susceptibility of Janghung area in Korea by Lee et al. (2002).

A case study was conducted by Pistocchi et al. (2002) where they used different probabilistic models for landslide hazard maps generation for a hilly and mountainous region in the northern Apennines, Italy.

In Germichay watershed of Iran, Analytical Hierarchy Process (AHP) was used to identify the zone by Esmali et al. (2003).

The landslide susceptibility mapping of Tsugawa area of Agano River, Niigata Prefecture, Japan was carried out by Ayalew et al. (2004). The study was done in two levels of weightages as primary and secondary. The primary level
weights were rule-based. Ratings were given to each class of a parameter on the basis of a certain criterion. Here, the criterion was landslide density, a ratio between the area occupied by landslide pixels on a class of a certain parameter and the total area of that class, changed into percentage. The secondary-level (factor) weights were, however, opinion-based scores, which determined the degree of tradeoff of one parameter against another. The map prepared was found to be useful for identifying slope sectors liable to landslide on relative basis.

The bivariate and multivariate analytical techniques were carried out for landslide susceptibility mapping for the Asarsuyu catchment in NW Turkey by Suzen et al. (2004).

Ayalew et al. (2005) carried out a study on the occurrence of landslides in Sacto Island of Japan. Analytical Hierarchy Process (AHP) and logistic regression methods were used to produce the landslide susceptibility maps.

Moreira’s (2005) prepared a qualitative landslide susceptibility zonation map of a sector of the Rio Mendoza valley, Argentina by overlapping thematic maps of conditioning factors. The slope instability and lithology play a main role in identifying the destruction caused by the landslides in the area.

Landslide susceptibility zoning of capital Cekmece area in the west of the Istanbul metropolitan area was conducted by applying the logistic regression by Moreira’s (2005).

Univariate and Multivariate statistical analysis to develop a landslide susceptibility model in analytical hierarchy process to define the factor weights was done by Komac (2006). This model deals with the quantitative analysis of
the occurrence and non-occurrence of landslides in variables of geo-environment conditions.

Komac (2006) has produced a landslide susceptibility map for the lower Mae Chaem watershed, Northern Thailand.

Mehdi Moradi et al. (2012) stated, susceptibility maps can be produced using the analytical hierarchy process (AHP). Eight thematic layers of landslide factors were deliberated and each layer is broken into smaller factors in this method, and they are weighted based on their importance, and the prepared layers are assembled and the final map is generated.

Hasekiogullari and Ercanoglu (2012) made a new approach to use AHP in landslide susceptibility mapping at Yenice (Karabuk, NW Turkey). They investigated the parameter effects in preparing landslide susceptibility maps with a data-driven approach.

Mondal and Maiti (2012) studied Remote Sensing Technique and GIS tools and prepared landslide susceptibility map of Shiv-Khola watershed, one of the landslide prone part of Darjeeling, Himalayas. 9 landslide inducing parameters were taken into account for this type of Analytical Hierarchy Approach (AHA). Using this tactic, pair-wise comparison of the factors was done and quantification of the factors was accomplished on priority basis. Couple comparing matrix of the factors were being made with reasonable consistency. Then Shiv-Khola watershed was classified into seven landslide susceptibility zones and the result was verified by ground truth assessment of existing landslide locations in the area. Here, the
classification accuracy was 92.86 and overall Kappa statistics was 0.8919 respectively.

Thanh and De Smedt (2012) analyzed landslide manifestation in Luoi district, Thua Thien Hue Province, Vietnam. Causative factor maps are derived using slope angle, weathering, land use, geomorphology, fault density, geology, drainage distance, elevation, and precipitation parameters. These maps are combined using AHP process for landslide susceptibility mapping. A four class susceptibility map was prepared with low, moderate, high and very high zones classification respectively.

Feizizadeh and Blaschke (2013) sorted three different GIS-MCDA methods and applied to landslide susceptibility mapping for the Urmia lake basin in northwest Iran. Weighted overlay techniques such as analytic hierarchy process (AHP), weighted linear combination (WLC) and ordered weighted average (OWA) were applied and landslide susceptibility maps were produced. An existing inventory of previously occurred landslides within the study area was compared with the resulted susceptibility maps. The AHP method performed best in the landslide susceptibility mapping closely followed by the OWA method while the WLC method delivered significantly poor results.

Setayeshirad et al. (2013) investigated the landslide susceptibility in the southern coast of the Caspian Sea, located in the northern part of Iran. The results indicated that the map obtained using m = 1 and t = 5 m compared with other maps has more compliance with the area. This map comprises five susceptibility ranges: very low, low, moderate, high, and very high. This map shows that high
percentage of the region (36 %) is subject to landslides. The landslide susceptibility map was verified using 69 older landslides in the area. The results indicated that most of the landslides in the area were concentrated in high and very high susceptibility classes.

Chen et al. (2014) applied a statistical model using geographic information system (GIS) to the Chencang District of Baoji, China. Landslide locations within the study area were identified using aerial photographs and detailed field survey. A total of 120 landslides were mapped, of which 84 (70 %) were randomly selected for building the landslide susceptibility model. The remaining 36 (30 %) were used for model validation. They considered a total of 10 potential factors that predispose an area to a landslide for the landslide susceptibility mapping.

Bayes Ahmed (2015), done landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh. Then, seven different landslide susceptible scenarios were generated based on the three weighted overlay techniques. The verification results showed satisfactory agreement (Feizizadeh et al. 2013) between the susceptibility maps produced and the existing data on the 20 historical landslide locations.