CHAPTER 5
DATA PREPARATION

5.1 General

When a rock has been disintegrated and decomposed by the process of weathering, weathered material soaked with rain water may slide down due to gravity. Such a sudden downward slip movement of rock debris is called landsliding. They can occur on any terrain given the right conditions of soil, moisture, and angle of slope (Praveen Kumar Rai et al., 2014).

Identification of area susceptible to landslide is crucial since urbanisation is increasing with time. The spatial information related to the causative factor for landslide can be derived from remote sensing and geographical information system (GIS) techniques. GIS a powerful tool for integrating different data type has made some significant development especially in spatial data analysis (Rawat et al., 2015).

The statically methods are based on relationships that have been observed between every factors that have contributed to present and past landslide distribution. All possible causative factors are evaluated and integrated using GIS technique for landslide susceptibility analysis. The reliability and capacity of functional method is depends on quantity and reliability of collected data. Bivariate, multivariate statistic and favourability functions are used to analyze the parameters of instability (Carrare et al., 1991). Landslide hazard has been evaluated by using various geological and other triggering parameters qualitatively (Hollings Worth and Kovacs, 1981; Keinholz et al., 1983; Seeley and West, 1990; Neeley and Rice, 1990; Montgomery et al., 1991; Anbalagan, 1992; Pachauri and Pant, 1992; Gupta et al., 1993; Hansen et al., 1995; Sarkar et al., 1995; Leroi 1996; Humbert, 1997; Nilsen and Brabb, 1997; Aleotti and Chowdhury, 1999; Guzzetti et al., 1999; Barredo et al., 2000; Dai et al., 2002; Moeyersons et al., 2004; Kanungo et al., 2006, M. H. Vahidnia et al., 2009, Ramlakhan Yadav and Dr. Neelam Rawat, 2016). These studies have used several variables as
landslide related factors of which slope, land use are always used other variables used were selected based on their relation with the landslide in a particular area. In the present study, slope, aspect, geomorphology, lineament density, distance from lineament, drainage density, distance from drainage, land use, distance from road and soil type was used.

Quantitative methods can demarcate the landslide prone zones more accurately and in qualitative methods also, different types of ranks and weightages were assigned (Carrara, 1988; Yin and Yan 1988; Bonham Carter et al., 1989; Agtenberg et al., 1990; Chung et al., 1995; Van Westen 1997; Aleotti and Chowdry, 1999 ; Luzi et al., 2000 ; Wu et al. 2000; Zezere 2002 ; Lee et al. 2002; Ohlmacher and Davis 2003; Van Westen 2003; Suzen and Doyuran 2004; Yesilnachar and Topal 2005 ; Saha et al., 2005; Van Westen et al., 2006 ; Gorsevski et al., 2006; Akgu and Bulut 2007; Greco et al., 2007 ; Lee and Pradhan, 2007 and Lee et al., 2007).

Probabilistic statistical methods used many researchers for prepared Landslide Susceptibility or Hazard or Vulnerability mapping using with different combination of causative factors. The statistical methods or deterministic method can be classified in to two types namely, i) Bivariate Statistical methods, ii) Multivariate statistical methods based on the method of deriving the quantitative contributions of the parameters. This study bivariate probabilistic analysis such as Frequency Ratio (FR) and Weight of Evidence (WofE) method used for produced landslide susceptibility map and the results are evaluated and compared.

5.2 Landslide Inventory Map

Landslide inventory maps show locations and characteristics of landslide that have moved in the past. Landslide inventory map provide useful information about the potential for future landsliding (Pattusamy S et al., 2014). Landslide inventory map forms the basis of investigation of landslides as the future landslides can occur in the same combination of physical and environmental conditions as in the past landslides
The landslide inventory map of the study area was prepared based on the landslide population map prepared by Geotechnical Cell, Department of Geology and Mining, Coonoor. The landslide inventory map of the area prepared by the interpretation of aerial photos was scanned and georeferenced. The landslide location was digitized by using of point data in ArcGIS tool. Also, the field visit has done and enquired the local peoples for the evidence of landslides. The sites were inspected to verify whether landslide has taken place. One hundred and two landslides have taken place in the study area during the landslide event in 1978 and 1979. The total study area of 134.9 km$^2$ and landslides have occurred in the four sub-watersheds and of these, the number of slides in Upper Coonoor is 28, Lower Coonoor is 9, Upper Katteri is 31 and Lower Katteri is 34. The landslide inventory maps for both the watersheds on colour codes DEM of the area are given in (Fig. 5.1).

Fig. 5.1: Landslide Inventory map of the Watershed overlaid on colour coded elevation image
In the study area, the Coonoor macro-watersheds can be divided into four sub-watersheds viz., Upper Coonoor, Upper Katteri, Lower Coonoor and Lower Katteri. And the area is selected for study as it is severely affected by landslides. The landslide location map (Fig. 5.2) shows that the most number of landslides occurrences in Lower Coonoor is North-Western part of the watershed and the elevation range from 340 m to 1450 m above MSL. The state highway road from Coonoor – Kattabettu – Kotagiri road passes through the area where the landslides occurrences are more. In the Upper Coonoor watershed the maximum numbers of landslides distributed in centre and Western part of the watershed at elevation between 1450 m and 2600 m. In Upper Katteri watershed the landslides distributed throughout the area and more distributed in North-Eastern part of the watershed. In the Lower Katteri watershed the landslides occurred throughout the area and most landslides occurred in South-Western part of the watershed. Considering the area of the watersheds and the number of landslides the hazard is more acute in the Lower Katteri watershed followed by Upper Katteri, Upper Coonoor and Lower Coonoor respectively.

**Fig. 5.2: Landslide location map of the Watersheds**
5.3 Landslide influencing Factors

Factors influencing to landslide occur by two categories viz., causative conditions and static condition. The selection of the variables depends on the conditions prevailing in the terrain which is investigated and availability of data. The slope, aspect, drainage density, distance from drainage, geomorphology, lineament density, land use, soil, distance from road and distance from lineament are the factors consider for the present study. The terrain conditions of the four watersheds are described in the following pages.

5.3.1 Slope

Slope is an important factor affecting slope stability (Anbalagan, 1992; Pachauri et al., 1998; Saha et al., 2002; Yalcin, 2008) since the driving force of mass movement increases with increasing slope (Guillard and Zezere, 2012).

As specified in the part of methodology chapter, Slope map of the study area derived from Digital Elevation model (DEM) created with elevation data used to generate the slope map using spatial analyst tool in ArcGIS. The 1:25,000 scales with 10 m contour interval gives the precision for assessing the landslide vulnerability of watersheds. The DEM was created from the elevation data using of spatial analyst tool in ArcGIS and the pixel size was kept as 30 x 30 m.

Slope is the common factor which influences the slope stability. The slope map (Fig. 5.3) for the study area ranges from 0 to 60° with steep slopes found in the major portion of the study area. Slope map is divided into 6 classes viz., 0 - 10°, 10 - 15°, 15 - 25°, 25 - 35°, 35 - 45° and 45 - 60°. The map shows that highest slopes ranging from 45 to 60° are found in the major parts of lower Coonoor watershed and other micro watersheds like upper coonoor, upper katteri and lower katteri are found very few areas.
The slope map shows that steep slopes of more than 45 degrees are found in close to the escarpments in the southern part of Lower Coonoor watershed and in the upper part of the Upper Katteri watershed. The map as the histogram shows (Fig. 5.4) that the relationship between landslides and slope angle which indicate most of the landslides were observed in the range between 10 to 15 degrees and dominate in all the micro watersheds.

In the study area 10 - 15° which covered 18% of the area with 36% of landslides followed by 15 - 25° forms 18% of the area with 29% of landslides, 0 - 10° cover 17% of the area with 20% of landslides, 25 - 35° which forms 16% of the area with 12% of landslides, 35 - 45° covers 16% of the area with 3% of landslides and 45 - 60° which forms 15% of the area with no landslides occurrence. It is observed that most of the landslides occurred within 25° and it is evident that above 25° slopes are restricted to landslides, since the area predominant with barren rocks are exposed.

Fig.5.3 Slope Map of the watersheds
5.3.2 Aspect

The aspect can influence landslide initiation. Water preservation and vegetation is imitated by slope aspect result to weakening the soil strength and influences of landslide. The aspect also plays important role in controlling some microclimatic factors such as rainfall intensity, exposure to sunlight and windward (wet) or leeward (dry) conditions, soil moisture, and weathering all of which control the material properties of the slope deposits (Dai et al., 2001; Cevik and Topal, 2003).

The aspect of a slope may also contribute to slope failure and has been used by several in landslide susceptibility analysis (Gokceoglu and Aksoy, 1996; Panikkar and Subramanyan, 1996; Lee and Min, 2001; Lineback, et al., 2001; Brardinoni, et al., 2003; Lan, et al., 2004; Lee and Choi, 2004; Gomez and Kavzoglu, 2005; Saha, et al., 2005; Wang and Sassa, 2006; Akgun, et al., 2007; Caniani, et al., 2007; Mathew, et al., 2007).

The aspect map (Fig 5.5) shows that the aspect is controlled by NW-SE trending ridges. The aspect map of the study was categorised into eight classes such as north, northeast, east, southeast, south, southwest, west and northwest with the addition of flat
area. Among these flat classes is a horizontal surface. The distribution of landslides also shows (Fig 5.6) that flat slopes have no landslides and southeast aspect have 21% which is the most dominant aspect classes of the study area followed by southwest 19% landslides, south 17% landslides, west 15% landslides, east 12% landslides, northeast 9% landslides, north 7% landslides and northwest 2% landslides. The relationship between the aspect and landslide occurrences in the study area shows that most of the landslides were observed in south facing slopes probably due to precipitation of rainfall more active in south west monsoon.

![Aspect Map](image)

Fig. 5.5 Slope aspect map of the study area
5.3.3 Drainage Density

The factors like Drainage density, length of streams per sq.km. also important factor controlling landslides. High drainage density and presence of deep narrow streams, which are often blocked due to erosion and deposition of debris, result in to flash floods and debris flows that trigger landslides (Pankaj Thapa, et al., 2015).

Most of the landslides have happened in the near to streams, hence has a strong control factor on landslide. Initially, erosion is high in head ward followed by toe and causing landslide (Pareek et al., 2013). The rainwater leads to percolation in poorly drained area. While distance from drainage is used by many workers, drainage density is also used (Mathew et al, 2007; Chauhan et al., 2010).

Drainage density is described as the ratio of sum of the drainage lengths in the cell and the area of the corresponding cell. Drainage density is also defined as the total length of channels per unit area (Long Khanh, 2008).
Drainage Density = \frac{\text{Total length of the channel (km)}}{\text{Unit area (km}^2\text{)}}

The drainage density map (Fig.5.7), of the study area shows that the maximum drainage density in the study area is 3.45 km/km$^2$. The higher drainage density occurred in SE part of the area followed by NE. The drainage density categorized in to 5 classes namely very low, low, moderate, high and very high. The moderate class drainage density covers 25% of the area with 27% landslides are dominant in density class followed by low drainage density covers 23% of the area with 23% of landslides, high drainage density covers the area 21% with 24% landslides, very high drainage density covers 16% of the area with 17% landslides and very low drainage density covers 15% the area with 10% landslides (Fig.5.8).

![Drainage Density Map](image)

**Fig. 5.7 Drainage density map of the study area**
5.3.4 Distance from drainage

The distance from drainage is an important factor and when the distance from drainage increases, the percentage of landslide generally decreases. This can be attributed to the fact that terrain modification caused by gully erosion may influence the initiation of landslides (F.C. Dai and C.F. Lee, 2002).

The distance from drainage map prepared using spatial analyst tool of ArcGIS (Fig. 5.9). The map subdivided in to five classes viz, 0 -50 m, 50-100 m, 100-150 m, 150-200 m and 200-600 m. Most of the landslides occurred within a distance of 100 m from the streams. These indicate that erosion action of the stream is influencing the landslides and this pattern resultant with drainage density and areas with more streams have more landslides.

The areas with 0 - 50 m class forms 30% of the area with 35% landslides, followed by 50 - 100 m which is 25% of the area with 28% of landslides, 100-150 m
which forms 19% of the area with 25% of landslides, 150 - 200 m which is 14% of the area with 7% of landslides and 200 - 600 m class which is 12% of the area with 5% of landslides (Fig.5.10).

Fig. 5.9 Distance to Drainage map of the study area
5.3.5 Lineament Density

The lineament is a linear feature of the terrain which includes faults, fractures, ridges, major discontinuities etc, (Sarkar, et al., 1995). The presence of lineaments also may greatly affect the stability of rock masses (Andreas and Allan, 2007). Numerous terms have been used to describe lineaments, e.g. geologic lineaments, tectonic lineaments, photo lineaments, fracture traces and photo linear or geophysical lineaments, based on the assumed origin of the feature or sometimes the data source from which it has been derived (Sander, 2007).

Hobbs (1904) as the first proposed term lineament, defined lineament as linear feature of terrain caused by fault, fractures, discontinuities, etc., revealing the architecture of the rock basement. O’Leary et al., (1976) recognized the lineaments as mappable, simple or composite linear features of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs from the pattern of adjacent features and presumably reflects some subsurface phenomenon. Lineaments are

Fig. 5.10 Percentage of landslides and area in each distance from drainage class
remotely sensed linear features on the Earth's surface that may or may not have a geological basis (Degnan and Clark, 2005).

Remote sensed lineaments are often used as indicators of major fractures in the near-surface (Juhari and Ibrahim, 1997). Lineaments can be exposed in both aerial imagery and in space images as a discontinuity that is darker or lighter in color in differentiation with the surrounding area. Parsons and Yearley (1986) provided that every satellite image has its ability to show unique lineaments that could be different from others.

Lineament has been used as an important factor (Anbalagan and Singh, 1996; Nagarajan et al., 2000; Saha et al., 2002) for landslide vulnerability studies. Most drainage pattern follows major lineament trends (Süzen and Toprak, 1998; Ramli et al., 2010) and this is true in the case of a soil covered terrain like Nilgiris, wherein valleys with straight alignment define lineaments.

The lineament layer was vectorised in ArcGIS from satellite imagery using Landsat ETM+ FCC image. The lineament density map was generated by using density tool in extension spatial analyst of ArcGIS. The lineament density map (Fig. 5.11) of the study area grouped into five classes viz., very low, low, moderate, high and very high among these classes, areas with very low lineament density forms 53% of the area with 32% of landslides followed by moderate lineament density forms 8% of the area with 27% landslides, high lineament density which forms 9% of the area with 25% of landslides, low lineament density forms 25% of the area with 11% landslides, and very high lineament density which is 5% of the area with 4% of landslides (Fig.5.13).
Fig 5.11 Lineament density map of the study area
5.3.6 Distance from Lineament

As the distance from lineament becomes smaller, the fracture of the rock masses and the degree of weathering increases resulting in greater chances of landslide occurrence (Farrokhnia et al., 2010). Lineaments represent faults and fracture zones and are observed in satellite data. They are one of the landslide causative factors particularly in areas of active tectonics like Himalayas (Chauhan et al., 2010). Most of the lineaments identified in the area trend in NE – SW and NW – SE direction. The distance from lineament map (Fig. 5.13) prepared using spatial analyst tool of ArcGIS software. The distance from lineament classified into 7 classes with 100 m interval and most of the landslides occurred very near to the streams i.e., less than 100m.

The areas with 0 - 100 m class forms 19% of the area with 26% landslides, followed by 100 - 200 m which is 17% of the area with 16% of landslides, 200-300 m which forms 15% of the area with 16% of landslides, 300 - 400 m which is 14% of the area with 11% of landslides, 400 - 500 m class which is 13% of the area with 14% of landslides, 500 - 600 m class which is 12% of the area with 13% and more than 600 m class which is 11% of the area with 5%.

Fig. 5.12 Percentage of landslides and area in each lineament density class
The map of the histogram shows (Fig. 5.14) that the percentage of landslides higher in the distance ranges between 0 and 100m. The other classes correspond to less number of landslides.

Fig. 5.13 Distance to lineament

Fig. 5.14 Percentage of distance from lineament classes in the watersheds
5.3.7 Geomorphology

The geomorphology plays important role of causative landslides, which has already been established by other researchers (Glade and Crozier, 2010). The landslides have been identified by various phenomena as sources of sediment, transportation agents, and demonstration of land degradation and ecological change Crozier (2010).

Geomorphologic factors plays vital role which induces the landslide in the study area. The study area (Fig. 5.15) is divided into four geomorphic units such as deflection slope, highly dissected plateau, moderately dissected plateau and valley fills by (Seshagiri et al., 1983). Highly dissected land form is the dominant class followed by, moderately dissected plateau, deflection slope and valley fill.

The histogram (Fig.5.16) outlined that highly dissected plateau covers 40% of the area with 69% landslides, followed by moderately dissected plateau occupying 24% of the area with 19% of landslides, deflection slope covers 23% of the area of 8% landslides and valley fills forms 13% of the area with 6% of landslides recorded.
Fig. 5.15 Geomorphology map of the watersheds

Fig. 5.16 Percentage of landslides and area in each geomorphology class
5.3.8 Soil Type

Soil is an important causative factor for landslide. The soil with more sand, instability slope and severe rainfall which constitute most dominant factors of landslide, cause severe damage to the land (Patanakanog, 2001).

Wieczorek et al., (1996) analyzed the effects of soil types on landslide occurrence. The authors identified that the occurrences of landslide mostly on unconsolidated till and clay deposits. According, Lakshumanan. C et al., (2012), the soil of Nilgiris district can be broadly classified into five major soil types viz., lateritic soil, red sandy soil, red loam, black soil, alluvial and colluvial soil. Major part of the district was covered by lateritic soil, red sandy soil and red loams are occurring as small patches.

The map of the study area shows that soil has classified into nine variables namely clay, clayloam, habitation, loam, loamysand, rockoutcrop, sandyclay, sandyclayloam and sandyloam (Fig. 5.17). The most dominant class loamy sand which covers 18% of the area with 45% landslides followed by sandy clayloam forms 16% of the area with 17% landslides, sandyclay covers 17% of the area with 16% landslides, rockout crop covers 10% with 15% landslides, habitation covers 10% of the area with 4% landslides, sandyloam forms 9% of the area with 3% landslides, loam covers 8% of the area with 1% landslides and clay and clayloam covers the area 6% and 5% respectively and not recorded any landslides (Fig. 5.19).
Fig. 5.17 Soil map of the watersheds

Fig. 5.18 Percentage of landslides and area in each soil class
The land use land cover map was vectorised from satellite imagery using Landsat ETM+ FCC image and the features were verified in the field. Land use and land cover dynamics of the Nilgiri district, characteristic of mountainous terrains. The elevation, typical weather and good rainfall supports evergreen forests called as shoals. Also the grasslands cover predominantly during the past. In Nilgiris district five hill tribes live on the isolated plateau namely Irulas, Badagas, Todas, Kotas and Kurumbas were using the forest crop for their food. They were hunters, and domesticated buffalos for dairy products, gathered honey, swidden or slash-and-burn cultivation was adopted on a small scale as the land is vast and population was limited it did not affect nature (Venugopal, 2004). There is still dispute about the Badagas origin whether they are native tribes of nilgiris like Todas and Kothas or migrated from Karnataka. Beginning of 14th century the Badagas tribes started the standard agriculture on a small scale.

The landuse started to change drastically, since the British peoples set their foot and they were occupied the forest and grassland and stimulate by natural process and are always ready to be occupied once again for cultivation. From the beginning of 19th century, the British colonizers started the developmental activities in nilgiris results; forest and grassland are transformed drastically in to tea and coffee plantation and other historical products. Also they launched numerous foreign trees, vegetables and fruits grow in suitable climatic conditions. Gradually the trend of decreasing the natural vegetation during post independence period on a accelerated phase. The settlement started to increase due to people’s migration from plains and establishment of small and large scale industries like Hindustan Photo Films, cordite factory, etc., and remarkable growth of tourism industry resulted in widespread urbanization of the province.

Lakshumanan et al., (2012) outlined that landuse and landcover changes in nilgiris identified using multi-temporal Remote Sensing which clearly shows the extent of changes in different landuse features. Also he stated that the agriculture land and
settlement has increased drastically at the sum of reduction of forest plantation and partially of barren land. Major changes have also been noticed in forests especially open forest to dense forest and mixed forest.

The urbanisation of nilgiris district developed drastically and district profile of Nilgiris, (http://nilgiris.nic.in/images/districthandbook0809.pdf) for 2008 – 2009, state that the population of urban (4, 54,609) has exceeds than rural population (3, 07,532). The reason was development of tourism has established hotel, lodges, etc., results landuse changes. Settlements of Nilgiris district increased from 7.49 km² to 44.29 km² and the annual rate reached 1.02 km² every year from 1973 to 2009 (Lakshumanan et al., 2012). This unexpected development for settlement in the late 1980s and the earlier 1990s observed growth of tourism industry. (Venugopal, 2004).

Land use and Land cover are major constituent factor for landslides in the mountainous regions. It is learned from the history that the causes of landslides are human activities, conversion of natural forest to agricultural and settlement and combination with intense rainfall induce landslides in the Nilgiris district which emphasis on land use land cover pattern changes (Nalina P et al., 2014).

The land use and land cover of the study area classified into nine categories viz., Built-up, crop land, forest, forest plantations, land with scrub, tea plantations, tank bed cultivation, tank bed vegetation and reservoir (Fig.5.19). Of these various classes, tea plantation forms 36% of the area with 81% landslides which is major dominant class occurred landslides followed by built-up land covers 9% of the area with 8% landslides, crop land forms 8% of the area with 6% landslides, land with scrub covers 7% of the area with 3% landslides and remaining classes constitute less than 2% of landslides only (Fig.5.20). Though cultivation of vegetables involves regular disturbance to the lands due to ploughing and irrigation, landslides are less frequent as they are established in areas with gentle slopes by adopting contour cultivation.
Fig. 5.19 Percentage of landslides and area in each Land Use class

Fig. 5.20 Percentage of landslides and area in each Land Use class
5.3.10 Distance from Road

Distance from road is similar to the effect of the distance from drainage, occurrence of landslide along road and on the side of the slopes affected by roads (Pachauri and Pant, 1992; Pachauri et al., 1998; Ayalew and Yamagishi, 2005; Yalcin, 2005). A road constructed along slopes causes reduce in the load on both the landscape and on the toe of slope may develop some cracks. Although a slope is balanced before the road construction, some instability may be observed because of negative effects of excavation. Some landslides were recorded whose origin can be attributed to road construction (H. R. Pourghasemi et al., 2012).

Distance from road map (Fig. 5.21) was prepared by using multiple ring buffer techniques in ArcGIS spatial analyst tool and is classified 6 classes with 100 m interval and most of the landslides occurred very near to the road i.e., less than 100 m. The map of the histogram (Fig. 5.22) shows that the percentage of landslides higher in the distance ranges between 0 and 300m. The other classes correspond to less number of landslides.
Fig. 5.21 Distance to Road Map of the Watersheds

Fig.5.22 Percentage of Distance to road classes in the watershed