CHAPTER 2
LITERATURE REVIEW

2.1 Purposes for writing a literature review

Conducting a literature review provides ample information to the researcher and research groups in the field. The literature review is a “legitimate and publishable scholarly document” (Le Compte et al., 2003).

The landslides are frequently occurred in tropical countries owing to human activities for establishment of infrastructure in unstable slope. The main objective of the study is to prepare the landslide susceptibility map in which areas with different degree of landslide susceptibility are demarcated. A detailed review was carried out on international and national literature to understand the existing status in the field and to develop appropriate methodology for the present study.

2.2 Landslide identification and mapping

Landslides are important geomorphic agents that reshape the landscape and transform local topography by transporting material away from its source. Cruden (1991) defines landslides as the movement of a mass of rock, debris or earth down a slope caused by the action of gravity. Sudden and rapid landslide events are often associated with fatalities, environmental degradation, and different types of damage to businesses, buildings, roads, public utilities, and disruption to people and the environment that cost millions of dollars annually. Landslides can be identified and mapped using a variety of techniques (Guzzetti et al., 2000), including: (i) geomorphological field mapping (Brunsden, 1985; 1993), (ii) interpretation of vertical or oblique stereoscopic aerial photographs (Rib and Liang, 1978; Turner and Schuster, 1996), (iii) surface and subsurface monitoring (Petley, 1984; Franklin, 1984), and (iv) innovative remote sensing technologies (Mantovani et al., 1996; IGOS Geohazards,
such as the analysis of synthetic aperture radar (SAR) images (Czuchlewski et al., 2003; Hilley et al., 2004; Singhroy, 2005), the interpretation of high resolution multispectral images (Zinck et al., 2001; Cheng et al., 2004), and the analysis of Digital Elevation Models (DEMs) obtained from space or airborne sensors (McKean and Roering, 2003; Schulz, 2004, 2005; Catani et al., 2005). Historical analysis of archives, chronicles, and newspapers has also been used to compile landslide catalogues and to prepare landslide maps (Reichenbach et al., 1998; Salvati et al., 2003, 2006).

Ardizzone et al., (2007) studied identification and mapping of recent rainfall-induced landslides using airborne Lidar. Result the high resolution DEM was compared to the pre-existing, coarser resolution (10m X 10m), DEM10 to establish how well the two digital representations of topography captured the topographic signature of landslides. The finding has implications for the recognition and mapping of landslides, and may lead to the automatic or semi-automatic extraction of landslide features from high resolution DEMs obtained from Lidar elevation data.

Bruce d. Malamud et al., (2000) Identify the total number of landslides that occurred over geologic time, and how many of these have been erased by erosion, vegetation, and human activity. We have also considered three rock fall-dominated inventories, and find that the frequency–size distributions differ substantially from those associated with other landslide types. We suggest that our proposed frequency–size distribution for landslides (excluding rock falls) will be useful in quantifying the severity of landslide events and the contribution of landslides to erosion.

Aerial photographs should be taken immediately after the event in evergreen forests as a palaeoscars are re-vegetated within few years. But with the launch of satellites which can capture high resolution data, with stereo pair capabilities, it has become possible to acquire multi-date data and assess landslides in inaccessible terrains.
However, in rugged forest watershed, canopy cover, it is very difficult to identify the small landslides (Brardinoni et al., 2003).

Fall et al., (2006) studied a multi-method approach to study the stability of natural slopes and landslide susceptibility mapping. Analysis of the results shows that the slides were influenced by the geotechnical properties of the soil, the weathering, the hydro geological situation, and wave erosion. The multiple factors affecting stability and serves the optimization of planning and investment for land development in the city and the elaboration of stabilization measures according to the instability factors.

These were concentrated in six different geomorphic–geologic– anthropogenic settings. A spatial database, which included 2252 landslides, was developed and analyzed using ASTER satellite imagery and geographical information system (GIS) technology. Landslides occurred particularly in moderate elevations on south facing slopes. Shrub land, grassland, and also agricultural land were highly susceptible to failures, while forested slopes had few landslides. One-third of the study area was highly or very highly susceptible to future land sliding and requires immediate mitigation action (Ulrich Kamp et al., 2008).

2.3 Landslide Susceptibility Zonation

Ramli et al., (2010) Although it is understood that there are many other factors which need to be taken into account in landslide assessment, it is considered that lineament interpretation has a vital role to play and is probably worth more effort in terms of its interpretation. It is suggested that before lineament interpretation is undertaken, the drainage pattern is first analyzed so that general lineament pattern.

Landslide Susceptibility Zonation methods and followed a probabilistic method, following a ‘pixel based calculation’ approach. This analysis establishes for each pixel, the joint probability that a landslide would occur for each class of each factor (the same meaning as a susceptibility index, or density) and given the probability that this pixel is located within the given class (Van Westen, 1993).
Sarkar and Anbalagan (2008) made a macro-level landslide hazard zonation for the area south of Alaknanda River covering 80 km². They first prepared a facet map of the study area with natural topographic boundaries like hill ridges, spurs, streams and major slope breaks. Their study shows that the preparations of Macro Hazard Zonation (MHZ) Map for the area using the same techniques provided a better assessment of landslide potential zones and give more information.

Uromeihy and Mahdavifar (2000) a good correlation has been shown between the landslide hazard zonation map produced for the Khorshrostam area and the actual occurrence of landslides in this region. the surface distribution of landslides represented by the surface percentage index (SPI) it has been shown that the lithology is the most important factor affecting landslides in the area, where the less resistance rock units such as the acidic volcanic rocks of Late Eocene age and the marlstones, sandstones and conglomerate of Neogene age are very susceptible to landslides.

Arora et al., (2004) an artificial neural network helps for landslide hazard zonation. In this study, an ANN has been applied to generate an LHZ map of an area in the Bhagirathi Valley, Himalayas, using spatial data prepared from IRS-1B satellite sensor data and maps from other sources. The accuracy of the LHZ map produced by the ANN is around 80% with a very small training dataset. The distribution of landslide hazard zones derived from ANN shows similar trends as that observed with the existing landslides locations in the field.

The factors of slope angle, lithology, and distance from a major geological discontinuity, land use, drainage, relative relief, and existing landslides all contribute to slope instability. These are analyzed in relation to landslide frequency and are numerically weighted based on their relative importance. The results obtained in the study have shown that the very high and high instability zones are nearer to the North Almora Thrust; this is obviously due to the tectonically active area and to the presence of loose powdery material as a result of the shearing effect (Sarkar et al., 1995).
Chang-Jo f (2003) The spatial databases usually contain map information on lithologic units, land-cover units, topographic elevation and derived attributes and the distribution in space and in time of clearly identified mass movements. In prediction modeling we transform the multi-layered database into an aggregation of functional values to obtain an index of propensity of the land to failure. The strategy proposed in this contribution wants to set up the terms to correctly apply quantitative models to generate, visualize and validate predictions by partitioning the database in time or in space. Ranking is the analytical technique for assessing and empirically comparing the results of the different predictions. Such results, evidently, are only meaningful in relative terms.

The mapping uses statistical methods replacing the conservative of geomorphic techniques. A detailed description on the history of the application of statistical methods in landslide analyses is presented by Carrara et al., (1995). It provides a critical review of almost all appropriate existing statistical methods (Havenith et al., 2005). Another significant study is by Guzzetti et al., (1999), in which the efficiency of various methods was assessed by comparing the results with each other.

2.4 Qualitative Landslide Assessment

Enrique A. Castellanos Abella (2008). The different landforms and the causative factors for landslides were analyzed and used to develop the heuristic model. The model is based on weights assigned by expert judgment and organized in a number of components such as slope angle, internal relief, slope shape, geological formation, active faults, distance to drainage, and distance springs, geomorphological subunits and existing landslide zones. The hazard map was then divided by two scales, one with three classes for disaster managers and one with 10 detailed hazard classes. The range of weight values and the number of existing landslides is registered for each class.

The verification result of frequency ratio model, showed 80.03% and 86.41% prediction accuracy in susceptibility and hazard maps respectively. Therefore, using
precipitation data, the influence of factors on the landslide susceptibility map can improve the prediction accuracy 6.38% in the landslide hazard map. The landslide hazard map was overlaid on the settlement map to produce the landslide risk map. These results can be used as basic data to assist slope management and land use planning. The methods used in the study are also valid for generalized planning and assessment purposes, although they may be less useful on the site-specific scale, where local geological and geographic heterogeneities may prevail (Saro Lee and Biswajeet Pradhan 2006).

Papathoma-Kohle (2015) Studied loss estimation for landslides in mountain areas an integrated toolbox for vulnerability assessment and damage documentation. The tool offers also a solution to one of the most common challenges in risk assessment, which is the lack of adequate data. Although the toolbox is an important step towards loss estimation at local level for debris flow hazards, there is still a need for continuous research in the field, in order to better understand the interactions between natural processes and the built environment, so that we are able to reduce the vulnerability of elements at risk and eventually the costs related to natural disasters.

Multiscale data derived from the commonly available DEM provides a reliable surrogate. The MCE utilizing Analytical Hierarchy Process (AHP) and weighted linear combination (WLC) methods were applied successively to study areas with cell resolutions of 50 m, 10 m, and 1 m. Careful consideration was given to the definition of relevant parameters across different scales since the size of each grid cell is a limiting factor for certain parameters. The multiscale GIS-based MCE approach can be useful for planning landslide mitigation studies beginning at a regional scale and proceeding to finer scales because the results at varying scales will have different impacts on the decision-making process (Suzana Dragicevi et al., 2015).

A qualitative risk assessment was carried out by combining susceptible areas and cultural heritage objects. As there were very limited historical data available on the occurrence of landslides and snow avalanches, a combination of local and expert
knowledge has been used to extract information on both cultural heritage and natural hazards. This method also combines state of conservation of cultural heritage objects with hazard information in a SMCE multicriteria evaluation environment, which could be easily integrated in a cultural management plan. Heritage management as a process that aims at protecting properties and places, which have historical and cultural significance, should take into account the threat posed by natural hazards. The inclusion of a section on natural hazards and disaster risk in cultural heritage conservation plans should be mandatory (Antoni Alcaraz Tarragüe et al., 2012).

Statistical approaches are a mainly probabilistic method which provides the relation between various factors individually and the distribution of landslides (Van Westen et al., 2005; Fell et al., 2008). This method is used in data integration techniques in a geographical information system (GIS) environment where the factors maps are integrated with this landslide inventory map to achieve the probability of each factor map on the basis of landslide distribution (Van Westen et al., 1993).

2.5 Quantitative Landslide risk Assessment

Bell and Glade (2004) studied Quantitative risk analysis for landslides. Risk analysis, beside risk evaluation and risk management, is part of the holistic concept of risk assessment. Within this study, risk analysis is considered only, focusing on the risks to life. To calculate landslide risk, the spatial and temporal probability of occurrence of potential damaging events, as well as the distribution of the elements at risk in space and time, considering also changing vulnerabilities, must be determined. The resultant maps show areas, in which the individual risk to life exceeds the acceptable risk so that for these locations risk reduction measures should be developed and implemented. It can be concluded that the newly developed method works satisfactory and is applicable to further catchments in Iceland, and potentially to further countries with different environmental settings.

The reliability of Quantitative risk analysis comes with the rigout of the assessment and the use of data, techniques and procedures that are appropriate to the
problem at hand. State-of-the-art Quantitative risk analysis and GIS tools, together with rigorous geotechnical input and the use of quality data, have been adopted in the study. The Quantitative risk analysis results provided sufficiently reliable estimates of landslide risk supporting cost-benefit analyses and risk management decisions (Ian Muir et al., 2006).

Although only landslide risk is considered the framework is generally applicable to other types of risk assessment in geotechnical engineering. For this study, consequence is assessed by computing the volume of the sliding mass. A more complete assessment of consequence would model the dynamic behavior of landslides. The framework is generally applicable, and the landslide risk assessments of two typical slopes are presented (Huang et al., 2013).

Magnitude recurrence relations were tentatively established for the two main slope processes such as landslides on the hill slopes and large debris flows extending out from the gully systems on to the plains. From the recurrence relations, landslide hazard (H) was estimated as the annual probability of a point being impacted by a landslide. The nature, number (E) and geographic distribution of the elements at risk were obtained by interrogating the GIS, and their vulnerabilities (V) to destruction by the two main landslide slope processes were assessed. Landslide risk may increase as development extends further into the hill slopes. Large debris flows could impact on subdivisions at the base of the slopes (Marion Michael-Leiba et al., 2002).

The most popular method adopted to land susceptibility mapping are statistical methods, Frequency Ratio, Weights of Evidence and Logistic regression. Among this frequency ratio method is a simple technique and has been adopted to evaluate the landslide susceptibility in several areas. Methods like multivariate adaptive regression splines (MARS), classification and regression trees (CART), and maximum entropy (MAXENT) were rarely used (Felicisismo et al., 2012).
2.6 Vulnerability Assessment

Thomas Glade (2003) detailed the vulnerability of each element at risk is assumed to equal total damage, a more elaborate concept of landslide vulnerability is applied in the Iceland case study. Although differing in complexity, both approaches demonstrate the advances in, and the necessity for, application of vulnerability assessments to landslide risk analysis.

Dai et al., (2002) suggest that the concept of landslide susceptibility in a subjective manner which mainly depends on the historical damage records, traffic density, run-out distance of landslides, its volume, velocity of sliding, nature of type of elements at risk and their proximity to a slide.

Kaynia et al., (2008) made of probabilistic assessment of vulnerability to landslide. This is based on the First-Order Second-Moment (FOSM) approach, which allows for the quantification of uncertainty from the input parameters up to the vulnerability estimates. Results on the application of the method show vulnerability estimates for susceptible categories on structures and people for prescribed study areas. These are given in the form of expected values and ranges of variation, according to uncertainty measures given by intensity and susceptibility parameters. Due to the expert-based nature of the vulnerability methodology, fine judgment is expected to accompany the interpretations.

Uzielli et al., (2008) developed based on quantitative approach for estimating the physical vulnerability of build areas. They proposed this method on the basis of landslide intensity and susceptibility of elements at risk, where landslide intensity is estimated on the basis of its destructiveness to any elements at risk which depends on velocity, run-out distance of the moving mass, unit discharge, and kinetic energy per unit area. The susceptibility of elements at risk in this literature refers to the spatial relation between the landslide mass and elements at risk.
According to (Suzen, 2002), the statistical methods are called as data-driven methods, which can be relevant in limited geographic extent. (Metternicht et al., 2005) suggest that, on the basis of statistical analysis of the factors that have led to landslide studies in past, quantitative prediction are made where the area having more landslides.

The statistical methods are the best method to evaluate where landslides occur predominantly and better understood of rock strength and structural pattern, etc. The application of landslide susceptibility and vulnerability maps for land use planning has increased significantly during few decades and attempt to prepare landslide susceptibility maps was made in several countries (Brabb, 1984; Nilsen et al., 1979; Varnes, 1984; Wagner et al., 1988) using GIS based analysis. The statistical methods can be classified into two types, based on the method of deriving the quantitative contributions of the parameters: 1. Bivariate Statistical methods, 2. Multivariate statistical methods.

2.7 Supervised Classification

The supervised classification can be attained through field work, aerial photographic study or other information sources and selecting representative pixels required for land cover types or classes (Lillesand, Kiefer et al., 2004.

Richards (1993), defined the supervised classification is a method for identifying spectrally similar areas on an image by identifying ‘training’ sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets. Also he discussed that supervised classification is the procedure used mostly for quantitative analysis of remote sensing data. It makes use of suitable algorithms to label the pixels in a given image as a representative of specific land cover types or classes. The supervised classification relies on the prior knowledge of the location and identify of land cover types that are in the image.
2.8 Statistical Methods

Statistical methods are being widely used to prepare landslide Susceptibility Maps adopting GIS methods. According to (Suzen, 2002), the statistical methods are called as data-driven methods, which can be relevant in limited geographic extent. (Metternicht et al., 2005) suggest that, On the basis of statistical analysis of the factors that have led to landslide studies in past, quantitative prediction are made where the area having more landslides

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2.8.1 Bivariate and Multivariate statistical methods

The proposed strategy includes four steps: (i) identification of the best response variable (RV) to represent landslide events, (ii) identification of the best combination of predictive variables (PVs) and neo-predictive variables (nPVs) to increase the performance of the statistical model, (iii) evaluation of the performance of the manuscript simulations by appropriate tests, and (iv) evaluation of the statistical model by expert judgment. The structure of the statistical relation between RV and PV is studied through multiple correspondence analyses to identify the class of PVs influencing the location of landslides. Based on the results, neo predictive variables (NPVs) with geomorphological meanings are proposed, and introduced in the statistical models. The use of bivariate statistical models based on both expert knowledge and
objective calculations for landslide susceptibility assessment, assuming the use of specific statistical tests if only a few landslide data are available. The proposed procedure has to be tested in other types of environment in order to verify its spatial robustness (Thiery et al., 2008).

Althuwaynee et al., (2014) studied a novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process. Result models 1 and 3 predicted 82.3% and 80% of testing data during the analysis, respectively. Thus, Models 1 and 3 show better performance than LR. These resultant maps can be used to extend the capability of bivariate statistical based model, by finding the relationship between each single conditioning factor and landslide locations, moreover, the proposed ensemble model can be used to show the inter-relationships importance between each conditioning factors, without the need to refer to the multivariate statistic.

The 390 landslides identified from historical records in a 23 year period, 318 (80%) locations were used for the training of the model, while the remaining 80 (20%) cases were used for the model validation. Among the landslide-related factors, slope angle, slope aspect, curvature, altitude, distance to roads, distance to rivers, lithology, distance to faults, soil, landcover and NDVI were used for the determination of the weights. These latter were determined in three different ways, by considering 11, 7, and 4 factors, respectively. The results obtained with 7 factors (94%) were better than those of frequency ratio (93%) and logistic regression model (90%). Therefore, the study shows that results of ANN-derived LSI classification are comparable and slightly better than those obtained from frequency ratio and logistic regression model (BiswaJeet Pradhan and Saro Lee, 2010).

Multiple regression and discriminate analysis require normally distributed input variables (Suzen, 2002). Another multivariate statistical method called Logistic Regression (LR) analysis which does not require such normally distributed input
variables, has been worked by few researchers in recent past in worldwide (Ayalew and Yamagishi, 2005; Van Den Eeckhaut et al., 2006; Yesilacar and Topal, 2005).

Núria santacana et al., (2003), studied a GIS-Based Multivariate Statistical Analysis for Shallow Landslide. The results obtained using a random sample show that 82% of all the cells, and 90% of cells including slope failures, have been properly classified. A susceptibility map based on the discriminate function has given consistent results. The susceptibility assessment is very sensitive to the parameters selected. Compared to the traditional methods, the main advantage of the GIS-aided procedure is the rapidity provided by the automatic capture of parameters.

Ercanoglu et al., (2004) According to the results of factor analysis, the importance weights for slope angle, land-use, elevation, dip direction, water conditions and weathering depth were determined as 45.2%, 22.4%, 12.5%, 8.8%, 8.1% and 3.0% respectively. Also, using these weights and the membership values of each conditioning factor, the membership value for landslide susceptibility was introduced. In the study area, the lowest membership value for landslide susceptibility was calculated as 0.20. Consequently, combining all results, a landslide susceptibility map was obtained. Compared with the obtained map, a great majority of the landslides (86 %) identified in the field were found to be located in susceptible and highly susceptible zones.

2.8.2 Frequency Ratio Method

The frequency ratio method is the most generally used method for landslide susceptibility zonation. It determines the relationship between the areas where landslide have occurred and landslide causative factor. The relationship is quantified by the frequency ratio which is the ratio of percentage of landslides in particular class of the causative factors and the percentage of the class in the total areas.

Tareq H, Mezughi and Juhari Mat Akhir, (2011). According to Landslide Susceptibility Assessment using Frequency ratio model applied to an area along the E-W Highway. Relationship between landslides and instability factors was statistically
evaluated by frequency ratio analysis. The results suggested that distance to road, lineament density and slope gradient are the most important factors effecting landslides. The results of the analysis have been validated by calculating the AUC which shows an accuracy of 88.31% in the case of success rate curve and 84.68 % in the case of the prediction rate curve, indicating a high quality susceptibility map obtained from the FR model.

Natural and anthropogenic factors increased the damages resulted from landslides in the last years. Then hazard zoning was performed with two methods including Analytical Hierarchy Process and frequency ratio methods. According to the landslide distribution map and high frequency in 0-100 m distance from roads, it can be concluded that among linear factors like roads, faults and rivers, road construction has highest effect on landslide occurrence. Moreover, among the 6 remaining parameters, the geology has the highest effect on the landslide occurrence, because large number of landslides formed in Tirgan formations, which are susceptible to landslide and erosion (Mehdi Teimouri and Parviz Graee 2012).

Slope and distance from fault are important factors in the landslides. In this study, 5-10 and 20-25 degree slope. Melting snow cause to instability of hillslope in changed land use and this increases the occurrence of landslide. Of course, faults can increase this danger (distance of fault in 1250-1000 m. This method is recommended for other areas having similar conditions such as regions with 5-10 slope degree, changed land uses with relatively high precipitation (650 mm) and the region with loose geologically formations (Shabanzadeh Karim et al., 2011).

The frequency ratio model is simple; the process of input, calculation and output can be readily understood. The large amount of data can be processed in the GIS environment quickly and easily. The multivariate logistic regression model requires conversion of the data to ASCII or other formats for use in the statistical package, and later reconversion to incorporate it into the GIS database. In the case of a fuzzy logic model, the factors must have a normal distribution, whereas in the case of multivariate
regression analysis, the factors must be numerical. In other words, the dependent variable must be input as 0 or 1, for landslide susceptibility analysis (Pradhan, 2010).

Lee and Pradhan (2006) prepared the landslide vulnerability map for Penang area using frequency ratio method. In this method, they converted the susceptibility map into risk hazard map by overlaying the susceptibility map over rainfall map of the area. In the hazard map, the potential event and its probability of occurrence were combined. The hazard map thus prepared was overlaid on settlement, transportation network and facility centre maps to generate a landslide risk map. The frequency ratio is a bivariate statistical method that is simple to implement with accurate result Lee and Pradhan (2007).

2.8.3 Weight of Evidence method

This method was originally developed for mineral potential assessment (Bonham-Carter et al., 1998) and it has also been used in the landslide susceptibility studies. (Pradhan, Oh, et al., 2010) outlined the Weights of evidence model applied to landslide susceptibility mapping in a tropical hilly area.

The weights of evidence model have many advantages compared to the other statistical methods. Weights of evidence is a data driven method that is basically the Bayesian approach in a log-linear form using prior and posterior probability and is applied where sufficient data are available to estimate the relative importance of evidential themes by statistical means (Bonham-Carter 1994)

2.8.4 Logistics Regression

There are different methods to prepare landslide susceptibility maps. The use of logistic regression in this study stemmed not only from the fact that this approach relaxes the strict assumptions required by other multivariate statistical methods, but also to demonstrate that it can be combined with bivariate statistical analyses (BSA) to simplify the interpretation of the model obtained at the end. In susceptibility mapping, the use of logistic regression is to find the best fitting function to describe the
relationship between the presence or absence of landslides (dependent variable) and a set of independent parameters such as slope angle and lithology. Here, an inventory map of 87 landslides was used to produce a dependent variable, which takes a value of 0 for the absence and 1 for the presence of slope failures. Lithology, bedrock-slope relationship, lineaments, slope gradient, aspect, elevation and road network were taken as independent parameters. The effect of each parameter on landslide occurrence was assessed from the corresponding coefficient that appears in the logistic regression function. The interpretations of the coefficients showed that road network plays a major role in determining landslide occurrence and distribution. Among the geomorphological parameters, aspect and slope gradient have a more significant contribution than elevation, although field observations showed that the latter is a good estimator of the approximate location of slope cuts. Using a predicted map of probability, the study area was classified into five categories of landslide susceptibility: extremely low, very low, low, medium and high. The medium and high susceptibility zones make up 8.87% of the total study area and involve mid-altitude slopes in the eastern part of Kakuda Mountain and the central and southern parts of Yahiko Mountain.

2.8.5 Temporal Probability

Probability-based methods are advantageous for several reasons. First, they incorporate variability and uncertainty into the model, providing a quantitative assessment of threshold reliability (Bean, 2009). For instance, in both cases described above a deterministic threshold could be defined at the lower bound of the rainfall that triggered landslides. This way, however, the meaning of the threshold is ambiguous (what happens when the threshold is exceeded?) and uncertainty is unaccounted. A probabilistic analysis, including the distribution of non-triggering rainfall, is much more informative and is capable of assign reliability to a given threshold. Second, unlike the categorical forecast of deterministic methods, probabilistic models furnish a probability distribution of the forecast quantity thus providing a better ground for estimating extreme events (which correspond to the tail of probability distributions). Finally, probabilistic approaches are commonly used in quantitative risk assessment to
determine the confidence levels of the prediction (Refice and Capolongo, 2004). In this section we describe a method to determine probabilistic rainfall thresholds based on Bayesian theory. The probabilistic approach provides an objective way to define thresholds in complex cases when conventional methods become highly subjective.

Since rainfall induced landslides are induced features from the heavy rainfall, their recurrence is controlled by the repetition of the rainfall event. Therefore, we must know the probability of a rainfall recurrence or the rainfall values at a certain return-period. This may be obtained through a regular hydrological frequency analysis (e.g., Chow 1953; Fowler and Kilsby 2003) with a set of rainfall data from different rain gage stations.

The key factor for the evaluation of landslide risk assessment is based on the time of occurrence or the possibility of occurrence of a landslide in a particular time. It can be obtained by direct and indirect methods.

Indirect method of obtaining temporal probability for landslides can be estimated by deriving the relationship between the landslide trigger and the occurrence of landslide in the past (Jaiswal et al., 2009). This is based on various elements like, antecedent rainfall, rainfall duration, rainfall intensity which gives a threshold value for the minimum rainfall for which a landslide will trigger and on the basis of this threshold the return period is calculated for landslides.

Direct methods are data driven methods which basically runs on the basis of number of occurrences of an event. According to Crovelli (2000) and Guzzetti et al., (2005) used the Poisson probability model to found out the expected occurrence probability of landslide in an expected time. Various other researchers also use this model to find out the expected recurrence intervals of volcanic eruption (Nathenson, 2001), flood (Coe et al., 2000). According to Chakraborty, (2008) used Poisson probability model to found the expected landslide occurrence probability in a given time
period for a road corridor, where he divided the road section into 23 units and calculated the number of landslide occurrence for each road unit.