CHAPTER-II: LITERATURE REVIEW

2.1 Introduction of Hazard

The objective of this Chapter is to highlight the studies already done by different researcher scholars, scientists, engineers, and academicians considering various aspects. Review of literature helps in understanding the problem in both theoretical background, and the empirical works which has already been done. A literature review has been carefully arranged under sub-titles relevant for this present research. As such to give a proper insight into identifying a research problem and highlighting the objectives and also elaborating on the knowledge about the research.

Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation which may be natural, anthropogenic or socio-natural in origin. According to Alexandre (1993), the hazard is also defined as an extreme geophysical event that is capable of causing disaster including ill health and injury, damage to property, plant, products or the environment, production losses or increased liabilities. UNISDR (2004), defines hazards as a phenomenon that poses a threat to people, structures, or economic assets and which may cause a disaster which is either manmade or naturally such as geological, hydro-meteorological and biological occurring in our environment. Hazards can broadly be classified as natural or human-made. Natural hazards are associated with natural processes and phenomena whereas anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities. Some cases if hazards are termed as socio-natural which associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change. Hazards may be single, sequential or combined in its origin and effects, yet hazard is categorized by its location, intensity or magnitude, frequency, and probability. Biological hazards are also defined by its infectiousness or toxicity, or other characteristics of the pathogen such as dose-response, incubation period, case fatality rate and estimation of the pathogen for transmission, ECD, (2006), as shown in Table 2:1.
Table 2.1: Classification of Hazard

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Hazard Origin</th>
<th>Hazard Type</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Geological hazards</td>
<td>Earthquakes, Tsunami or Tidal wave, Mass earth movement such as landslides,</td>
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<tr>
<td></td>
<td></td>
<td>rockslides, subsidence, surface collapse, geological fault activity.</td>
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<tr>
<td>2</td>
<td>Hydro-meteorological</td>
<td>Floods, debris and mudflows, storm surges, thunderstorms, hailstorms,</td>
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<tr>
<td></td>
<td>hazards</td>
<td>rain and wind storms, blizzards and other severe storms, drought,</td>
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<tr>
<td></td>
<td></td>
<td>desertification, bush and wild fires, heat waves, sand and dust storms,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>permafrost, snow avalanches.</td>
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<tr>
<td>3</td>
<td>Biological hazards</td>
<td>Outbreaks of epidemic diseases, Plant or animal contagions, Extensive</td>
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<tr>
<td></td>
<td></td>
<td>infestations.</td>
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2.2 Mass Wasting/Movement

The geophysical system of the earth undergoes persistent changes through mass movement and other degradation processes through time and space. Structures, materials, processes and the history of changing landform are the four essential components of a study of the nature and origin of the present land surface (Selby, 2005). Geomorphological analysis deals with the study of physical attributes and their functional analysis involved in the landform development. The science of geomorphology has witnessed many new approaches and the uses of different tools and techniques for studying origin and development of the landscape. During the early days, geomorphologists depended mostly on the field description supported by some sketchy maps for the purpose. However, in the recent decades, the geomorphic information happening around the world is available or collected in the form of topological maps, satellite imageries, cadastral maps and aerial photographs involving a wide spectrum of electromagnetic radiation (Joshi and Tatak, 2006). Brunsden (1984) preferred the term mass movement and distinguished this from mass transport as being a process which did not require a transporting medium such as water, air or ice. The most active weathering takes place near the surface of the earth, where rocks are directly acted upon by solar insolation, atmosphere, hydrosphere, and biosphere and which results in the change that occurs in rocks and minerals, the decomposition and the formation of other rocks and minerals (Yakushova, 1986).
2.1.1 Types of Mass Wasting

Sharpe (1938) was the first to attempt a classification of the various types of mass wasting and he recognized four major classes of mass wasting designated as slow flowage, rapid flowage, landslides, and subsidence. The collective term for all gravitational or down-slope movement of weathered rock debris is termed as mass wasting by Bloom (1991), as shown in Table 2.1. The two major types of slides are rotational slides and translational slides. Rotational slides are where the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide whereas translational slides is that type of landslides where the landslide mass moves along a roughly planar surface with little rotation or backward tilting. Mass wasting has been classified in various ways depending on the type of motion, type of material involved, and rate of movement. Causes of rapid mass wasting were divided by Sharpe (1938) into passive and active or initiating causes. The passive causes include the lithological factors comprising of unconsolidated or weak materials or those which become slippery and act as lubricants when saturated with water. Varnes (1978) also classified mass movements into various types. Besides landslide, creep and debris flow are two important types of mass wasting. Figure 2.1, shows the different types of mass wasting.

2.1.2 Landslide Hazard

Landslide is a geomorphic process influenced by geomorphic features such as slope, drainage, weak geology, structure (faults, folds, etc.), lithology, relief, seismic and tectonic activities etc. Besides natural causes, intense and unplanned human activities also trigger landslides incidences. Landslides are down-slope movements of masses of rock debris or earth due to failure along weak planes when materials lose their shearing strengths. This may happen with or without the aid of excess water. Every mass beneath a slope has a tendency to slide downward and outward under the influence of gravity. If the shear strength of the soil adequately counters this tendency the slope is stable. Landslides may occur suddenly or through a prolonged period of time, with or without any apparent provocation. It is usually an annual and recurring phenomenon in hilly terrain most commonly occurs during the monsoon. The process of hill slope movement is generally known as “landslide” but variety and complexity of landslide phenomena are distinct and classified landslides into different types. (Crozier,1986) According to Caine and Mool (1982), most landslides are complex hybrids between several classes. Figure 2.2 shows the different parts of landslide process.
ROCKFALL
ROCKSLIDE
CREEP
DEBRIS SLIDE
SUBAQUEOUS SAND FLOW
BLACK SLIDE
DEBRIS FLOW
SLUMP

Figure 2. 1: Types of Mass Wasting (Source: USGS, 2004)
Figure 2.2: A complex rotational slump with an earth-flow as toe. *(Source: USGS, 2004)*

Table 2.2: Classification of landslides and related phenomena

<table>
<thead>
<tr>
<th>Nature and Rate of Movement</th>
<th>Glacial Transport</th>
<th>Fluvial Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperceptible</td>
<td>Solifluction</td>
<td>Earthflow</td>
</tr>
<tr>
<td>Slow to rapid</td>
<td>Creep</td>
<td>Mudflow</td>
</tr>
<tr>
<td></td>
<td>(rock creep, soil creep)</td>
<td>Debris Avalanche</td>
</tr>
<tr>
<td></td>
<td>Solifluction</td>
<td>Debris Avalanche</td>
</tr>
<tr>
<td>Slide</td>
<td>Debris avalanche</td>
<td></td>
</tr>
<tr>
<td>Slow to rapid</td>
<td>Slump</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debris slide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debris fall</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rock slide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rock fall</td>
<td></td>
</tr>
</tbody>
</table>
There are two basic types of landslides. The first category includes those slides due to mechanical causes including an increase in hydrostatic pressure and erosion. In the second category are those slides caused by changes in the physical and/or chemical properties of the soil. Generally, a decrease of shear strength in a soil is due to the clay mineral content. Clay minerals are responsible for the effects and the mechanism of water absorption, desorption, ion exchange, swelling, etc. in soils (Veder and Hilbert, 1980). Terzaghi (1950), discourses that where silt is inter bedded with sand, or clay with silt, water percolating through the coarser permeable units gets trapped above the fine-grained units. The resultant increase in pore pressure between the sand and silt grains forces the particles apart, reducing inter-grain friction. As gravitational forces acting on the grains are countered by increased buoyancy, the particles formerly stable on steep slopes, generally greater than 35°, becomes less stable and cause slope failure. Landslides may also occur as consequences of changes in landforms. Swanson and Swanson (1975), and Swanston and Swanson (1976), stating that forest destruction and road construction for initiating landslides. Bhandari (1984) to blames the man for his interference in the hill ecosystem that leads to a landslide. Sharma et al (1996) opine that landslides are amongst the most rapid of all mass movements and pose very great hazards in mountainous terrain. Landslides are common in active mountain belts where the terrain is young and research indicates that in mountain chains being uplifted landslides are inevitable (Petley and Reid, 1999). Major slides have occurred due to a combination of factors including thick deposits of unconsolidated material on steep hill slopes, adverse lithological and hydrogeological conditions, and anthropogenic activities such as road cutting, construction of heavy structures, etc. (Kumar et al, 1995). Valdiya (1987) study shows that poor road construction for causing destructive landslides as most roads are unimaginatively planned and very badly constructed. This has led to the destabilization of hillsides and production of large volumes of debris. According to Ives (1981), inappropriate construction of roads and buildings on the Himalaya region has led to greatly induce the incidences of landslides. Nilsen et al (1976), attributed varying combinations of various factors as responsible for landslides which may occur due to sudden or gradual changes on a slope. These factors may be the types and properties of the underlying bedrock, soils, and surficial deposits, angle and direction of slope, type of vegetation, amount and distribution of rainfall, types of construction, placement of cuts and fills, and the presence of past landslide deposits areas of abundant recent landslides are often noted in areas of abundant past landslide deposits and suggested that accurate mapping of these past deposits in conjunction with other factors such as slope angles and bedrock geology can yield significant data for regional analyses of slope
stability. Brabb et al (1972) and Nilsen and Brabb (1972) opine that the evaluation of any region should include an analysis of the slope stability characteristics of the terrain, incorporating factors such as the degree of slope, bedrock, soil characteristics, seismic triggering of landslides, and other factors. Sahai (1993) states that lithology, slope, poor vegetative cover, and abnormal rainfall bring about slope instability. Table 2.2 shows the different causes of the landslide.

According to Sharpe (1938) and Thornbury (1984), a landslide can be further classified into the following types:

i. Slump: It refers to the downward slipping of one or several units of rock debris usually with a backward rotation with respect to the slope over which movement takes place, hence also termed as a rotational slide.

ii. Debris Slide: It is a rapid rolling or sliding of unconsolidated earth debris without backward rotation of the mass.

iii. Debris fall: It is the nearly free falling of earth debris from a vertical or overhanging slope face.

iv. Rockslide: It refers to the sliding or falling of individual rock masses down the slope along the bedding planes, joints or fault surfaces.

v. Rockfall: It is the free falling of rock blocks over any steep slope. Rock falls are produced when solid material or soil become detached from a steep slope and then fall freely for some distance or bounce and roll down the slope.

Cruden and Varnes (1996) classified the causal factors of slope failure, including the precondition and triggering ones, into geological, morphological, physical and human causes (Table 2.2). Landslides are caused when the stability of a slope changes from a stable to an unstable condition. A change in the stability of a slope can be caused by a number of factors, acting together or alone. A landslide block moves as a unit or as a series of units along a well-defined plane, much of the material moving as a large slump block. The most important natural cause of landslides is an increase in the groundwater and water saturation decreases the shear resistance of the soil mass and increases the shear stress by increasing the weight of the soil mass (Bloom, 1991). Slope failure also occurs along with the rivers or torrents where the stability of the slope is damaged by the loss of support at its lower end. Landslides can also be triggered by earthquakes. In recent years, large-scale construction in mountainous terrain, particularly road and reservoir development, has become a major cause of landslides (Sthapit and Tennyson, 1991).
Table 2.3: Causes of Landslides

<table>
<thead>
<tr>
<th>Geological Causes</th>
<th>Morphological Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Weak materials</td>
<td>i. Tectonic or volcanic uplift</td>
</tr>
<tr>
<td>ii. Sensitive materials</td>
<td>ii. Glacial rebound</td>
</tr>
<tr>
<td>iii. Sheared materials</td>
<td>iii. Fluvial erosion of slope toe</td>
</tr>
<tr>
<td>iv. Jointed or Fissured materials</td>
<td>iv. Wave erosion of slope toe</td>
</tr>
<tr>
<td>v. Adversely oriented mass discontinuity</td>
<td>v. Glacial erosion of slope toe</td>
</tr>
<tr>
<td>(Bedding, etc.)</td>
<td>vi. Erosion of lateral margins</td>
</tr>
<tr>
<td>vi. Adversely oriented structural discontinuity (Fault, Unconformity, Contact, etc.)</td>
<td>vii. Subterranean erosion</td>
</tr>
<tr>
<td>vii. Contrast in permeability</td>
<td>viii. Deposition loading slope and or it's crest</td>
</tr>
<tr>
<td></td>
<td>ix. Vegetation loss</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Causes</th>
<th>Human Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Intense rainfall</td>
<td>i. Excavation of slope and toe</td>
</tr>
<tr>
<td>ii. Rapid snow melt</td>
<td>ii. Loading of slope or its crest</td>
</tr>
<tr>
<td>iii. Prolonged exceptional precipitation</td>
<td>iii. Draw down of reservoirs</td>
</tr>
<tr>
<td>iv. Rapid draw down of floods and tides</td>
<td>iv. Deforestation</td>
</tr>
<tr>
<td>v. Earthquakes</td>
<td>v. Irrigation</td>
</tr>
<tr>
<td>vi. Volcanic Eruptions</td>
<td>vi. Mining</td>
</tr>
<tr>
<td>vii. Freeze and Thaw weathering</td>
<td>vii. Artificial Vibration</td>
</tr>
<tr>
<td>viii. Shrink and swell weathering</td>
<td>viii. Water leakage from utilities.</td>
</tr>
</tbody>
</table>

Source: Cruden and Varnes, 1996; USGS, 2004 (cf. Sahoo, 2009)

The problems of landslide, subsidence and also erosion are quite common in the hilly terrain due to the combination of several factors like the geological movements in fragile geology and high steep relief, structure, lithology, fracture patterns, increased anthropogenic activities, water seepage, vegetation cover, weather and climatic changes (Asthana and Pal, 2006). Kumar, et al., (1995) and Cruden and Varnes (1996) insist that major slides occur due to a combination of thick deposits of unconsolidated material on steep slopes and adverse lithological, hydro-geological, and anthropogenic conditions. Rock falls pose severe hazards, particularly along transportation corridors in many mountainous regions. Although often involving only a small volume of material, the speed of rock falls and the hazard they pose to
motorists have prompted several state departments of transportation to support rock fall research. The science of rock fall mechanisms is relatively well understood, and several computer simulation programmes have been developed to aid in evaluating the hazard. However, improvements are needed in establishing standards for risk management and for certifying the effectiveness of rock fall barrier systems. This can be achieved by encouraging more widespread adoption of established techniques through technology transfer. In order to develop models for slope instability applicable over wide areas, there is a need to analyze the causal factors controlling the occurrence of landslides, hence the need to prepare the world landslide inventory. The Working Party’s working definition of a landslide is the movement of a mass of rock, earth or debris down a slope (Cruden and Varnes, 1996) and it recognizes that the phenomena described as landslides are not limited either to the land or to sliding. Gravity forces which decide the path of flow or sometimes triggering factor, the slope failure is the slope angle which induces by gravity forces. A large number of geomorphologic processes like soil formation and soil erosion depend upon the slope. The increase in slope gradient on hard rock results in highly unstable slope conditions on slope instability.

Landslide includes all varieties of mass wasting/movements on slopes (particularly hill slope). The materials are composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. It is also important to understand their relationship with meteorological factors, period of activity, existence of any warning sign, ground water conditions, chronology of topographic change or erosion by rivers, earthquakes, and other factors which may have a relationship with the slope deformation surrounding the investigation site area prior to the detailed investigation (Varnes, 1978). According to Petley and Reid (1999), landslides are inevitable in young mountain chains that are being uplifted. Nilsen and Brabb (1972) attribute various factors including bedrock, surficial deposits, slope, vegetation, rainfall, human activity and past landslide deposits as responsible for landslides. Rainfall is a recognized as a trigger of landslides, and investigators have long attempted to determine the amount of precipitation needed to trigger slope failures, a problem of scientific and societal interest. For rainfall-induced landslides, a threshold may define the rainfall, soil moisture, or hydrological conditions that, when reached or exceeded, are likely to trigger landslides. However, according to Bloom (1991), water plays an important role in mass-wasting by over-steeping slopes through surface erosion at their bases and by generating seepage pressure through groundwater flow. The high intensity of rainfall generally leads to increased landslide activity. Areas with high mean annual rainfall are generally associated
with abundant recent landslides. Crozier (1989) mentioned that compared with relatively longer periods of rainfall a landslide will occur during an intense rainfall of shorter periods pointing to a decrease in the shearing strength of the soil due to swelling. An individual landslide characteristically involves many different processes, operating together, often with different intensity during successive years. These activities are very common in mountainous terrain particularly during and also immediately after the rainy season (Bartarya et al., 1989; Gupta and Bist, 2004). Thong, et al., (2004), and Aier (2005) also conclude that during cloudbursts the damage is more as compared to prolonged wet spells. The addition of water on slopes due to rainfall triggers landslides. Percolation of runoff water in unsaturated zones in the weathered rock profile and its mechanism by rainwater resulting in the rise of groundwater table is explained by Khatsü (2011). The CRRI (2000) is of the opinion that in India the majority of landslide incidences fall into the category of rainfall-induced landslides. Sahai (1993), Ramasamy and Muthukumar, 2008; Anbazhagan and Sajin, 2011; Neelakantan and Yuvaraj, 2013, states that lithology, adverse slope conditions, poor vegetative cover, and abnormal rainfall bring about slope instability. A landslide would occur at the toe of a slope as soon as the driving forces exceed the resisting forces (Veder and Hilbert, 1980). The safety factor for a slope is the ratio of the sum of resisting forces that act to prevent failure to the sum of the driving forces that tend to cause failure. Failure will occur when shearing stress exceeds the shearing strength of the material. Translating the mechanics of a simple force model into the stresses operating in a hill slope, as the stress attributes acting on a point on a potential shallow slide shear plane. The shear stress promotes down-slope movement, assisted by water pressure within the hill slope. The shear strength of the slope material will prevent movement, until maximum shear stress is reached, causing the material to rupture, or fail (Selby, 2005). It is more appropriate to model landslide mechanics in terms of stress rather than force. Hill slopes typically behave as a continuum at scale, composed of continuous mass or arbitrary blocks of soil and/or rock, rather than discrete blocks on a plane, such as an object. Stress is a measure of the average force per unit area; the force is distributed continuously through a deformable body across imaginary internal surfaces which id stress tensor (Anderson and Anderson, 2010). Landslides can be studied from various points of view: firstly, as a part of the mass wasting process. In this context, the type, extent, distribution, intensity, frequency, age, the types of rock, structure, sliding materials, and causative and triggering factors are main aspects. Secondly, it can be studied from hazards perceptive where its impact on life and property is assessed. Within it, assessment of
risk and preparation of hazard zonation map are important aspects that can be followed by suggestions for mitigation of landslide hazards (Husain, 2008).

Using a method of analysis similar to infinite slope model, illustrate slope stability in terms of stress using a 3D slope segment from a planar hill slope.

![Stress path for a typical brittle (orange) and ductile (green) material](Source: Petley and Allison, 1997)

From the above Figure 2.3, explains the Stress path for a typical brittle (orange) and ductile (green) material such as (a) stress-strain curve illustrating key mechanical parameters; (b) brittle deformation; (c) ductile deformation. For (b) and (c): stage 1 = initial elastic phase, stage 2 = elastic plastic phase, stage 3 = steady state plastic deformation phase, stage 4 = strain weakening phase, stage 5 = residual, steady state phase (Petley and Allison, 1997).

Landslides occur when shear stress exceeds the shear strength of a slope material. Every mass beneath a slope has a tendency to slide downward and outward under the influence of gravity. Based on the factor of safety of the slope, which compares the shear strength and shear stress
existing on the slope material, it is possible to classify the slope into three stages as stable, marginally stable and unstable (Crozier, 1986). If a natural slope fails, it is much more probable that the failure has been caused by a gradual decrease of the shear strength, than by extreme conditions at the time of failure. The addition of water to a slope increases the load owing to the added weight of the water. The shear strength is reduced owing to the increase of the pore water pressure. Water, in fact, has been implicated as the main controlling factor in most slides. The balance of forces on a hill slope is considered using the factor of safety by calculating shear stress and shear strength, for an example hill slope and formulating an expression for the factor of safety and can conduct a sensitivity analysis for the purpose of assessing which variables are most important in determining hill slope stability. A threshold is a minimum or maximum level of some quantity needed for a process to take place or a state to change (White et al., 1996). A minimum threshold defines the lowest level below which a process does not occur and represents the level above which a process always occurs. Shear stress is the maximum permissible velocity is a spatial and temporal average for the cross-section of interest. Cross sections of very different shapes may produce the same average velocity, though forces exerted at the channel boundary (bed and banks), and how those forces affect boundary materials, may differ markedly (Theisen, 1992). For that reason, shear stress is a parameter that better represents hydraulic forces and therefore is more useful in calculating threshold conditions and determining appropriate channel lining materials than velocity alone. Stability threshold analysis for bank stabilization most often considers permissible velocity and shear stress thresholds together (Frothingham, 2008). Landslide calculations indicate that the maximum shear stress occurs at or close to the toe of a slope, the shear strength of the soil is first exceeded at this point and the failure then spreads up the slope (Broms and Wong 1991).

Nagarajan (2001) and Singh (2005), in geomorphology, landslides are one of the major mass wasting processes or mass movements that along with erosion and weathering sculpture the landscapes of the earth (Sajin and Anbazhagan, 2015) Landslides are the best manifestation of slope instability or slope failure and often occur at specific locations under certain topographic and geologic conditions (Husain, 2008). Deforestation allows water to seep into the soil and causes it to be eroded. Investigations have shown that deforestation can cause instability by inducing soil erosion and movement (Crozier, 1989). Several studies illustrate the stabilizing effect of tree roots, as the shearing resistance is increased due to the roots. Bishop and Stevens (1964) stated that in shallow-depth landslides that are confined to the root zone, the apparent cohesion of slope material is reduced with the gradual decay of tree
roots following deforestation. Gravity forces which decide the path of flow or sometimes triggering factor, the slope failure is the slope angle which induces by gravity forces. A large number of geomorphic processes like soil formation and soil erosion depend upon the slope. The increase in slope gradient on hard rock results in highly unstable slope conditions on slope instability. Most of the new landslides are reactivated old failures in landslide terrain, and unless there are distinct causes, it is extremely rare that non-landslide terrain fails. Those topographic characteristics can be interpreted from aerial photographs, satellite imageries, and topographic maps, and be verified through field investigation.

Guzzetti (2000) explains that topographic parameters such as slope gradient and slope aspect play a crucial role in steep mountainous terrain for influencing mass movement process and proposed that the major assumptions for identification and mapping of landslides can be:

i. Landslides leave typical signatures on the terrain surface, i.e., they refer to changes in the form, position or appearance of the topographic surface.

ii. The morphological signature left by a landslide can be interpreted to determine the extent of the slope failure and to infer the type of movement (e.g. fall, flow, slide, complex, compound etc.) and the rate of movement.

iii. Landslides are controlled by many terrain factors and are a combined result of the interplay of physical processes and mechanical laws that can be determined empirically, statistically or in a deterministic fashion.

iv. Landslide occurrence follows the principle of uniformitarianism, where he summarises that the present is the key to the topographic wetness and that processes occurring in the present were the same processes that had operated in the topographic wetness and would be the processes that operate in the future.

2.3 Recent trends in the study of landslides

Studies on a landslide in India have started long back in 1880 with the pioneering work by Oldham (1980) on the stability of the hill slope of Nainital town. The first major initiative to pool the work on Indian landslides was made jointly by Central Building Research Institute (CBRI) and Central Road Research Institute (CRRI) by hosting an International Symposium on Landslides in 1980 at New Delhi. Ever since, the event has been institutionalized by the International Society of Soil Mechanics and Geotechnical Engineering as a four-yearly event (Bhandari, 2006). The abundance of clay, rock clay, and marl, together with the presence of
high relative relief and of a chaotic lithological and structural setting, contribute to the occurrence of numerous large landslides in India (Guzzetti et al., 1999), which has resulted in presence of high landslide density in the country.

Research on a landslide in India received a great consideration of the world in the year 1994 when the Ministry of Agriculture, Government of India, presented a report in the Conference related to the International Decade for Natural Disaster Reduction (IDNDR) held in Japan. According to Rao (1989), five major regions in India are susceptible to landslides, viz.,

i. Western Himalaya Mountain (Jammu & Kashmir, Himachal Pradesh and Uttar Pradesh (now Uttarakhand)).
ii. Eastern and North Eastern Himalaya (Arunachal Pradesh, Sikkim, and Darjeeling West Bengal)
iii. Naga-Arakkan Mountain Belt (Nagaland, Manipur, Mizoram, Tripura).
iv. Plateau Margins in the Peninsular India and Meghalaya in the North-Eastern part of India.
v. Western Ghats Region in the western part of the Indian peninsula.

In the hilly terrain of India, the Himalayas, the Western Ghat, Eastern Ghat and Aravallis landslides have been a major and widely spread natural disaster which often effect life and property and causes a major concern. The two regions most vulnerable to landslides are the Himalayas and the Western Ghats. The Himalayas mountain belt comprises tectonically unstable younger geological formations subjected to severe seismic activity. The Western Ghats and Nilgiris are geologically stable but have uplifted plateau margins influenced by neo-tectonic activity. Compared to Western Ghats region, the slides in the Himalayas region are huge and massive and, in most cases, the overload along with the underlying lithology is displaced during sliding particularly due to the seismic factor. Landslides Zonation Mapping is a modern method to identify landslides prone areas and has been in use in India since the 1980s. The major parameters that call for evaluation are as follows:

i. Slope-Magnitude, length, and Direction
ii. Soil thickness
iii. Relative relief
iv. Land use
v. Drainage pattern, and density
vi. Landslide-affected the population.
According to the Geological Survey of India (2001), a landslide is a frequently occurring natural hazard in the hilly terrains of India that shows a high proportion of activity during the monsoon period from July to September and after the snow fall from January to March. The strong earthquakes also cause a landslide, particularly in regions marked by critically disposed and unstable slopes. On a rough estimate, nearly 15 percent of India’s landmass or 0.49 million sq km area is prone to landslide hazard. This includes 0.098 million sq km of the North Eastern Region, comprising the Arakan-Yoma ranges, and 0.392 million sq km of parts of the Himalaya, Nilgiri, Ranchi Plateau and Eastern and the Western Ghats. As many as 20 states of India are affected by different degrees of landslide hazard. Of these, the states of Sikkim and Mizoram have been assessed to be falling under very high to severe hazard classes. Most of the districts of the states of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Nagaland, and Manipur come under high to very high landslide hazard classes. In the Peninsular Region, the hilly tracts of states like Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Goa, Madhya Pradesh and Kerala constitute low to moderate hazard-prone zones.

2.4 Application of Remote Sensing and GIS

Several researches and scientist, spanning nearly for four decades, attempted Landslide Hazard Zonation by Cartographic methods. Remote Sensing and GIS with the advancements in technology has enhanced development in various fields of landslide assessment. One of the major factors is the slope assessment. Slope surfaces may be divided into different categories related to stability if the required information on terrain characteristics is available. Geographic Information System (GIS) provides a powerful framework for the integration of different types of spatial data obtained from diverse sources. It also gives users the ability to handle and analyze the spatial data more efficiently and accurately as well as to generate new spatial information by integrating the existing ones. Geographic Information Systems (GIS) is defined as a computer-based system for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modelling and output, with its excellent spatial data processing capacity, which is of great use in aspect to natural disaster assessment (Carrara et al., 1991). The scarce availability of spatial data in developing countries makes remote sensing (aerial photography, satellite imagery) useful to acquire this information in an appropriate cost/time ratio. GIS has strong functions for spatially distributed data processing and analysis. The GIS database is
developed from drawings and image files. These datasets are converted to GIS compatible mode by scanning, digitization, etc. GIS plays an important role in developing and tailoring integrated spatial datasets, including remote sensing derived thematic layers, for input to models. The rich set of spatial data requirement forges fundamental links between GIS, remote sensing, and environmental models. Remote sensing complements GIS by providing the framework for integrated spatial analyses of diverse data structures in order to help understand and parameterize land surface processes. Using GIS gives the possibility to integrate qualitatively as well as quantitative data for geospatial analysis for evaluation. The application of GPS is also important for locating landslide sites. Deformations caused by high-risk slopes have to be mentioned. The measurement of superficial displacements is the simplest way to observe the evolution of a landslide. GPS is a useful tool has increased role to play in landslides monitoring studies. Regarding productivity, accuracy, motion capability, rapidly and economy according to the size of the study area, GPS techniques are similar and often better than classical geodetic survey techniques. In addition, GPS facilitates the study of large areas without any direct line of sight between measurement sites. The main advantage of GPS sensors compared to conventional deformation monitoring sensors is that GPS requires no line-of-sight between the stations. This enables GPS to monitor the landslides even during unfavourable weather conditions either in real time or post-processing mode. The patterns of resource use and resource demand are constantly changing. Currently, the skill to acquire data about land uses associated to resource development is refining as of current technological developments in remote sensing equipment, interpretation techniques, and data processing (National Research Council, 2005).


At large and site-specific scales, process models are in use that simulates the spatial distribution of the factor of safety using slope stability models (Wu and Sidle, 1995; Van Westen et al., 1997). The database is a collection of information about certain parameters and their relationships to each other. To monitor and understand the dynamic processes as well as to develop environmental simulation models for scientific assessment many diverse types of datasets are necessary. The models require data on the multi-temporal behaviour of land surface properties as well as the parameterization of spatially diverse and complex landscape characteristics. These use an integrated system approach for landslide hazard modelling across multiple time and space. Based on sources of acquisition, GIS data may be classified as spatial and attribute. Topographical and thematic data are classified as spatial data whereas field and collateral data are grouped as attribute data. Aldridge (1999) developed a methodology to generate a digital database.

Spatial entity types are the basic topographical properties of location, dimension, and shape. Such data are represented on a map or in a GIS as a point, line, or area features. Spatial data are stored in graphic files and managed by a file management system. The two models that represent the spatial component of geographic information are vector and raster. The relationship between spatial data and landslide occurrences contained in GIS database can be used to map potential landslide zones (Malkawi, et al, 2000). Various integration techniques and models are also discussed by Bhan and Champati (1998). Attribute data describe the
characteristics of spatial features. The data file can be described in terms of records, fields, and keys. Field data is acquired through field surveys by recording information on landslide events.

Satellite data products are being frequently used in landslide mapping and hazard zonation (Varnes, 1984; Nabil, 1989; Van Westen and Terlien, 1996). Hansen (1984) discussed direct and indirect mapping methods for landslide hazard. The structural, and land use and land cover maps are generated with the help of satellite imageries using visual interpretation techniques with standard basic and key elements to extract information. After interpretation, the paper-based maps are scanned and digitized to create a digital database for GIS analysis and modeling. The satellite imagery is then overlain by the transparency from which lineaments and land use and land cover features are extracted and transferred. The doubtful areas due to similar spectral response and signature identified during preliminary image classification are listed out before ground verification where the areas are then physically verified in the field (McKean, et al, 1991). Based on the ground information, corrections and modifications are made for the final structural map, and land use and land cover classification.

Although all known methods have their own advantages and disadvantages, utilization of quantitative methods has become preferred and more commonly used in recent years. Landslides are considered as one of the major natural disasters, which result in the substantial loss of life and damage to communication routes, human settlements, agricultural and forestland. Large portions of the terrain in mountainous areas have been subjected to slope failures affected under the influence of a variety of terrain factors and figured by events such as extreme rainfall or earthquake. Advancement in remote sensing technology enables us to identify the finer features on the terrain and to create high-resolution Digital Elevation Model (DEM). Most of the landslide modeling using GIS involves contour interval of 20 meters or 10 meters. The thematic maps generated from satellite imageries data of resolution 30 meters and 5.8 meters. GIS is generally not used as an analysis tool but as a data management tool (Balamurugan, et al, 2016). Geological formations of different lithologic groups that are combined with slope categories, below and above the critical, have been used to prepare Landslide Hazard Zonation maps by Blanc and Cleveland (1968) for Southern California. The San Francisco Bay region was studied by Nilsen and Brabb (1972) using maps showing geological formations, slope ranges, and landslide debris to prepare a Landslide Zonation map. On the basis of percentage of outcrop area of a formation occupied by landslide debris in combination with slope categories, Brabb et al (1972) have rated the slope stability of
geological units in San Mateo County. Radbruch and Crowther (1973), in California, classified the area on the basis of lithology and the number of landslides present. In the United States, Radbruch et al. (1976) considered the frequency of slope failure in different groups of geologic units. A similar grouping of lithology and mass movements was used by Rodriguez et al. (1978) in southern Spain.

2.4.1 Landslide Hazard Zonation

In recent days, several approaches and techniques are projected to analyse the different causative factors of landslides and create maps representing the probability of occurrences of similar hazard in near future. Hansen (1984), Varnes (1984), Van Westen (1993), Soeters et al., (1991) divided these methods into direct and indirect. In the direct method, geophysical mapping consists where the earth scientist evaluates the direct relationship between the hazard and the environmental setting throughout the survey at the site of the hazard event. This approach was defined by Kienholz (1978), which is based on the topographic wetness and present landslides which are identified and expertise opinion of the occurrences sites where events are most likely to occur with the reasoning of likeness. The decision making is therefore difficult to formulate, as events vary from place to place. It not necessary for the digitizing of many different maps but, the detailed fieldwork requires a substantial quantity of time investment. Thereby, the accuracy of the resulting hazard map will completely depend on the skill and experience of the expertise.

Different methods for landslide susceptibility zonation have been suggested where the simplest is the distribution analysis only depicts direct mapping of landslide locations from field surveys or aerial photographic interpretation. Thus do not provide information on the predictive behavior of future landslide activity. In this type of method, GIS is used to digitize landslides prepared from field survey maps, aerial photographs, and remote sensing images. In qualitative analysis, subjective decision principles are applied to characterize weights and its ratings based on the experience of experts (Saha et al., 2002). Remote sensing and GIS techniques may be used here for thematic map preparation and overlay analysis.

There is a progress in the preparation of landslide susceptibility maps because of the development of technology. The fundamental objective of the landslide susceptibility is to reduce the impact of landslides by determining the areas at risk (Sema, et al., 2017). Geographical Information Systems and Remote Sensing techniques have proved to a great degree in preparing these kinds of maps. Information is gathered and analyzed by utilizing
RS techniques, as indicated by statistical criteria, it is likely to store, process, and analyze a large amount of complex data successfully in a very short time using GIS techniques. Preparation of landslide inventory and susceptibility maps is one of the most important stages in landslide hazard mitigation. These maps provide basic information to different policy makers for future urban development and land use planning. Furthermore, effective utilization of these maps can extensively reduce the future damage potential and other cost effects of landslides. Landslides and its consequences is generally still a major problem for many countries, especially in India due to rapidly increasing populations which leads to increasing demand for space.

Recently, a number of different methods and techniques have been created to prepare and predict landslide hazards zonation. Broadly it can be divided into two groups such as qualitative methods and quantitative methods which vary from experience-based analyses to complex mathematical, logical, and computer-based systems to analyse landslide susceptibility, hazard, and risk. Geomorphological analyses and direct field mapping methods are considered as qualitative methods because they don’t yield numeric output with reference to landslide assessment. On the other hand, quantitative methods such as deterministic analyses, probabilistic approaches, statistical methods, and artificial intelligence techniques mostly depend on mathematical models and produce numeric outputs. Yet after all the advancement there is still no general agreement has been reached yet about the best method for producing landslide hazard assessment maps. The ultimate purpose of landslide susceptibility zonation (LSZ) is created to the identification of landslide occurrence places over a region on the basis of a set of selected internal and external different causative factors (Kanungo et al., 2009). Therefore, the LSZ of any region involves landslide inventory mapping and determination of different causative factors.

2.4.2 Landslide Inventory Mapping

Landslide inventory map is the simplest form of landslide mapping (Guzzetti et al., 1999). The landslide inventory is the most important factor comprising the information and delineates about the existing as well as topographic wetness landslide occurrences in the area and it incorporates the data of area, time, type, expand, relative age (extremely old, old, recent), level of movement (dormant and active), estimates the depth of landslide (Galli et al., 2008; Santangelo et al., 2015). Thus, landslide inventory mapping is also termed as 'landslide map' (Van Westen et al., 2008). Landslide Inventory map helps to comprehend frequency of
landslide in a region and give reliable data to develop landslide susceptibility model (Guzzetti et al., 2012; Van Westen et al., 2003). There are different methodologies that might be conventional or modern techniques to develop landslide susceptibility model for the duration of the time. The conventional strategies include visual explication, field study, historical data etc. While the modern techniques incorporate semi-computerized basing on spectral and altitude qualities. Therefore, a method of landslide inventory mapping depends upon the degree of the study region, scale; investigate purposes and accessible assets (Santangelo et al., 2015; Guzzetti et al., 2012).

A landslide can be distinguished by semi-automated classification based on the spectral and elevation characteristics. Van Westen et al., 2003, each landslide leave certain characters on the landscape that provides information for landslide exposure, such as disturbed or absent vegetation cover which is different from its surrounding, sudden modifications in slope, the existence of slope, disrupted drainage. Trace like large exposed in source zone, a narrow and elongated transport zone, lobate deposition area indicates earth flow (Keefer and Jhonson, 1983). The concave surface of falling-out indicates rotational landslide whereas the plane surface of falling-out indicates translational slide (Murillo-García et al., 2014). In active flow, the seasonal pattern of movement is found because of rainfall or snowmelt, groundwater and air pressure variation (Schuelz et al., 2009).

The other technique of landslide inventory mapping are field survey (GPS recording, interview, participatory mapping involving local people as well as geologist), historical studies (newspapers, books, information of landslide from road maintenance or organization), qualitative analysis ways (dendrochronology, radiocarbon dating, pollen analysis, lichenometry), monitoring networks (extensometers, surface tiltmeters, inclinometers, piezometers, network of electronic distance measurement, network of differential GPS measurement, network of Theodolite measurement, Ground-based INSAR, Terrestrial LiDAR) is helpful for obtaining detailed information of landslide (Giordan et al., 2013). Therefore, based on purposes, the landslide inventory map is classified into several ways such as reconnaissance inventory maps, geomorphological inventory (Duman et al., 2006), and multitemporal map. Reconnaissance inventory map was based on the basis of the type of prevalent movement of landslide such as rock fall, debris flow, rotational slide, translation slide, complex slide etc (Galli et al., 2008). It also included the position of the escarpment, badlands and alluvial fans (Guzzetti and Cardinali, 1989). Geomorphological inventory mapping included local geomorphological setting such as erosion, deposition, and change in
altitude of slope, lithology and structural setting and escarpments, trenches, hummocky topography, back slopes (Santangeloa, 2013).

2.4.3 Landslide inducing factors

The most important stage of LSZ is to develop causative indicators in a form of spatial data layers. These data layers are related to geology, geomorphology and topography of the region and selection of each indicator lie in the requirement to present condition. In general, data source related to lithology, structure, slope, drainage, vegetation cover, soil types and thickness, land cover, rainfall, ground water, and seismicity are commonly used. Crozier (1986) classified the responsible factors for the occurrence of the landslide by three-way i.e. the preparatory factors, triggering factors, controlling factors. Preparatory factors include the inherent characteristics of the region which make land unstable without actually initiating it. It involves lithology of slope material, geomorphic and structural features, geology, hydrogeologic condition, vegetation of the region. Triggering factor is the force to hit the slope and initiate it to be unstable and seismicity, rainfall, undercutting by the river and human activities (land use change, unplanned construction), are regarded as triggering factors (Kanungo et al., 2009).

2.5 Methods of Hazard/Susceptibility Zonation mapping

The methods of landslide susceptibility zonation (LSZ) are effectively in the present days for a better understanding of landslide and the mechanism. In the resent topographic wetness different approaches for LSZ methods and techniques have been derived which is broadly classified as qualitative and quantitative approaches.

2.5.1 Qualitative approaches

The qualitative approach is subjective where knowledge and experience of experts play a pivotal role to generate landslide susceptibility mapping. The qualitative approach includes both direct and indirect methods. The direct method comprises field survey, interpretation of aerial photograph and historical data of landslides was proposed by Verstappen (1983) and involves landslide inventory on two methods such as based analysis and geomorphic analysis. The landslide inventory-based methods analysis the distribution of landslide attributes in spatial and temporal aspect (Abella, 2008). The attributes of landslide include different types, subtypes, composition, the density of mass movements and different causal factors. Since it
signifies detail nature of landslide region; it requires detail records of historical landslides and field study. This method was followed by geomorphic analysis by Chang-Jo (1999) which is directly based on the detail geomorphological map and it directly involved expert to assess landslide susceptibility on the basis of their experience of the field. The main advantage of this method, it allows a rapid assessment of landslide susceptibility of a certain region (Kanungo et al., 2009).

The indirect method deals with the identification and collection of information regarding causative factors which generate LSZ map. Heuristic approach is one of the indirect qualitative method in which the causative factors are weighted by experts according to expected importance in causing landslides and most of the work was done between 1970 to 1990 in this method viz, Carrara and Merenda (1976), Fenti et al., (1979), Kienholz (1978), Ives and Messerli (1981). In heuristic approach, various methods for determining subjective decision rules were vogue in the field of landslide hazard zonation i.e. BIS (Bureau of Indian Standard), GSI (Geological Survey of India) Method, Analytic Hierarchy Process (AHP) method, Weighted Overlay Method (WOM). BIS (Bureau of Indian Standard) was propounded by Anbalagan (1992) and in this method, broadly six causative parameters were taken up namely lithology, structure, slope morphology, relative relief, land use land cover, hydrological condition. Each parameter has a certain rating which is called maximum LHEF (Landslide Hazard Zonation Factor) rating. As for example, lithology, structure, slope morphology, land use land cover has ‘2’ and relative relief, the hydrological condition has ‘1’. As for external factors, seismicity and rainfall are determined. The LSZ is prepared by a combination of all rating of thematic factors associating with each facet of the region. Following the method, many types of research were done by Sharma and Mehta (2012), Anbazhagan and Ramesh (2014). Singh (2010) used GSI method using ten parameters which is the modified from BIS guidelines (1998). In this method slope erosion condition, average rainfall and landslide were taken as an extra parameter.

The Analytic Hierarchy Process (AHP) was first introduced by Thomas Saaty (1980), which is an effective tool for managing complex basic decision making and may help any decision makers or policy makers to set needs and settle on the best choice. Deduction of the complex decision to a development of pairwise correlations, and later integrating the outcomes, the AHP yields both subjective and objective parts of any decision. According to Banai (1993), AHP is considered an arrangement of assessment criteria, and an arrangement of option choices among which the best decision is to be made. It is essential to note that, since a portion of the criteria could differentiate, it is not valid when all is said in done that the best
choice is the one which advances every single criterion, rather the one which accomplishes
the most appropriate exchange off among the distinctive criteria (Wu, 1998; Basnet et al.,
2001, Zhu and Dale 2001). The AHP creates a weight for every assessment basis as indicated
by the chief's pairwise examinations of the criteria. The higher the score, the more important
and effective is the relating criterion. Next, for a settled foundation, the AHP allocates a score
to every choice as per the researcher’s pairwise examinations of the choices in view of that
paradigm (Balamurugan, et al., 2016). The higher the score, the better the execution of the
alternative as for the considered rule. At long last, the AHP consolidates the criteria weights
and the alternatives scores, along these lines deciding a worldwide score for every choice,
and an ensuing positioning. The worldwide score for a given choice is a weighted total of the
scores it got as for every one of the criteria.
Furthermore, the AHP model consolidates a helpful method for checking the consistency of
the decision maker's assessments, thus lessening the inclination in the process of decision
making. The AHP model is an extremely adaptable and effective device on the grounds that
the scores, and consequently the last positioning, are gotten on the premise of the pairwise
relative assessments of both the criteria and the choices gave by the researcher. The
calculations made by the AHP are constantly guided by the chief's involvement, and the AHP
can consequently be considered as an instrument that can decipher the assessments (both
subjective and quantitative) settled on by the leader into a multi-criteria positioning. Also, the
AHP is basic on the grounds that there is no need of building a perplexing master framework
with the chief's learning installed in it. Then again, the AHP may require countless by the
researcher, particularly for issues with numerous criteria and choices. Although each and
every assessment is exceptionally basic since it just requires the leader to express how two
alternatives or criteria contrast with each other, the heap of the assessment assignment may
get to be distinctly nonsensical. The quantity of pairwise examinations develops quadratically
with the number of criteria and alternatives (Malczewski, 1999). For example, when looking
at 10 choices on 4 criteria, $4 \cdot 3/2 = 6$ correlations are asked for to assemble the weight vector,
and $4 \cdot (10 \cdot 9/2) = 180$ pairwise examinations are expected to manufacture the scoring
framework. Be that as it may, so as to decrease the leader's workload the AHP can be totally
or incompletely computerized by determining reasonable edges for naturally choosing some
pair-wise correlations (Eastman et al., 1993). Figure 2.4 shows the Saaty’s scale for
influencing parameters of landslide process based on weightages assessment.
Figure 2.4: Saaty’s scale for assignment of weights

The weighted overlay is also a qualitative method in which various thematic maps are combined and overlaid to prepare hazard zonation map. In this method, the weight of each factor is also assigned according to field condition and expert experiences. Sarkar and Kanungo et al., (2004), Panikkar and Subramaiyan (1997), applied this method for LSZ in GIS platform. The only disadvantage of these qualitative methods is the dependency of subjective decision rules which led to subjective biases.

2.5.2 Quantitative Approaches

The quantitative approaches were adopted to produce an LSZ map in order to minimize subjectivity in weight assignment process and quantify the relative importance of various causative factors in objective ways (Kanungo et al., 2009). The quantitative approaches include numerous statistical methods. In the, topographic wetness two decades the statistical methods are further facilitated due to the advancement of computing technology and rapid progress in the field of Remote Sensing(RS) and Geographical Information System (GIS) (Ray, 2007). The main objective of this approach is to predict dependent variable on the basis of a set of pre-determined independent variables. Where the selection of variables and its weight of parameter is dependence on the basis of landslide distribution studies of the particular region. Its main principle lies to indicate the landslide favorable zone which may be free from current landslides but existed condition may be a push to future instability. In this approach an investigator can assess factors related to landslides according to the condition of the study area and as well as can validate the importance of their chosen factors
(Aleotti and Chowdhury, 1999). The statistical analysis encompasses both bivariate methods (weight of evidence modeling, frequency ratio, Information Value, Relative Effect) and multivariate method (discriminant analysis, regressive multiple analysis).

In the bivariate method, the weight of each thematic class is determined by existing landslide density in each individual class. The weight evidence model is one of the bivariate statistical methods which are based on Bayesian theorem model adopting of log-linear version. Its idea is based on the prior and posterior probability. It is undertaken two types of variables called response variable or depended on variable and predictor variable or depended on variable. In literature of landslide susceptibility zonation, response variables had been considered as landslides and analyst variable had been considered as causal factors. Due to different degrees of association between response variables and predictor variables the outcome may be positive or negative with varying magnitudes.

Symbolically, it can be defined as –

\[ w+ = \ln \frac{P(B|D)}{P(B|-)} \]  \hspace{1cm} (Eq.1)

\[ w- = \ln \frac{P(B|-)}{P(B|D)} \]  \hspace{1cm} (Eq.2)

Where, ‘B’ is the class of causal factors (independent factors)

‘D’ is the landslide (dependent factors)

‘-’ is the absence of any above two i.e causative factors or landslide.

The degree of association between two variables signifies by contrast value. The contrast values accept and reject the independent variables. At last by a combination of independent variables the probability of occurrence of the landslide is determined. Bonham-Carter (1994), Carrara et al., (1995) and Thiery (2004), applied this method for landslide susceptibility mapping.

Frequency ratio is also a bivariate probabilistic which predicts non-occurrence of landslide area on the basis of landslide occurrence area under certain circumstances. This method was adopted in landslide studies by Yilmaz and Keskin (2009), Ehret (2010), Kannan et al., (2012), Ramesh and Anbazhagan (2015). The basic logic behind the frequency ratio is that landslide occurs due to some or similar factors in a region which is practically determined by
the ratio of the area where landslide occurred and total study area for a certain factor of causing a landslide.

Multivariate statistical methods emphasize the relative contribution of each causative factor to the whole susceptibility within the domain of region. The whole procedure of multivariate statistical analysis involves several steps such as classification of stable and unstable zones on the base of landslide pixels, preparation of matrix on the basis of presence and absence of landslide pixels in a given category of a given thematic layer, multivariate statistical analysis and susceptibility zonation based on the result (Aleotti and Chowdhury, 1999). Since these methods involve a large volume of data, external statistical packages are also used to support GIS packages (Kanungo et al., 2009). The multiple statistical methods like discriminant analysis and logistic regression analysis are widely vogue in the field of landslide susceptibility zonation. Logistic regression was first propounded by Cox (1958). It adopts logistic function to measure the relationship between the categorical dependent variable and independent variable which may be one or more than one. So, it may be binomial when two variables are considered and as outcome, there have two types of possibilities for a dependent variable. On the other hand, it may be multinomial when more than two variables are considered and as outcome three or more than possibilities are derived. In logistic regression arbitrary code are used like "1" and "0". "1" represents the observed outcome as significant possible outcome. So, it referred to as a “success” or a “case”. Whereas, the contrary outcome (“non case”) is denoted as "0". In a case, logistic regression predicts the odds value which is defined as the "ratio of the probability that something occurs to the probability that it does not occur"(Ohlmacher and Davis, 2003).

2.5.3 Distribution-Free Approaches

Distribution-free approaches are developed to overcome the limitation of qualitative approaches and quantitative approach. The qualitative approach is overwhelming depend on the expert’s opinion whereas the quantitative approach is highly objective due to depending on data character. Distribution-Free Approaches brazes the two opposite approaches. This approach is regarded as a useful alternative when the character of landslides is nonlinear and causative factors are uncertain in LSZ mapping. In this approach, weights are computed in an objective manner, but it is free from any distributional assumption of data (Kanungo et al., 2009). Fuzzy set theory and artificial neural networks (ANNs) are the distribution-free approaches which is adapted for LSZ mapping generally in the regional scale. Cascini et al.,
1991 discussed five operators, namely the fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum and fuzzy gamma operator. This study uses the fuzzy algebraic sum, the fuzzy algebraic product, and fuzzy gamma operator for combining the fuzzy membership functions.

### 2.5.4 Fuzzy Inference System

Zadeh (1965) was the first to introduce the fuzzy set theory to analyze mathematically non-discrete natural processes or phenomena. A fuzzy set is a class of objects with a continuum of grades of membership, characterized by a membership function which assigns to each object a grade of membership ranging between zero and one (Zimmermann 1996). In fuzzy set theory, membership values were assigned in between 0 and 1 reflecting the degree of certainty of influencing factor in landslide susceptibility. The membership values 1 and 0 contribute the maximum and minimum or nil influence of landslide susceptibility of a particular influencing factor respectively. In landslides susceptibility mapping, all the classes of the nine thematic causative factors are considered as a member in the set of landslide susceptibility area. The fuzzy membership value can be derived from different method like normalization of frequency ratio (Lee 2007, Pradhan et al., 2009; Ramesh and Anbazhagan 2015; Rohan Kumar and Anbalagan 2015; Balamurugan, et al, 2016; Sema, et al., 2017) and information value (Yin and Yan 1988), the cosine amplitude method (Ercanoglu and Gokceoglu 2004; Kanungo et al., 2006), or subjective based (Bonham-Carter 1994; Tangestani 2004; Champatiray et al., 2007; Ray et al., 2007). Different operators can be employed to combine the membership values when two or more thematic maps with fuzzy membership functions.

### 2.6 Landslide Accuracy Assessment

Prediction model only has scientific significance when the assessment is done with scientific validation. In landslide studies, prediction model is constructed on the basis of the similar condition of topographic wetness landslide phenomenon. There are various validation methods like Receiver Operating Characteristic (ROC) or Area Under Curve (AUC) and Relative Density Index (R-index) are used commonly in the literature of landslide susceptibility mapping.
ROC curves analysis is one of validation method where the probabilistic events are assassin the accuracy level of a diagnostic test (Egan, 1975). ROC curve is a graphical representation which shows the performance level of prediction and classifier system. In the graphical platform, the curve is plotted with true positive value (X-axis) against false positive value (y-axis). A true positive value indicates the prediction of a particular event for a location where this event occurred. The false positive signifies just its opposite case i.e falsely predicted event response. In many literatures, ROC methods have been used for detection of success rate and prediction rate of landslides. Generally, the collected data are partitioned on the basis of time or space. The time partition one set of data is used for prediction image and another set of data is used for validation of prediction model. Success rate indicates a "goodness of fit" by assuming the model as correct (Chung and Fabbri, 1998). It helps to determine how well the resulting hazard map has classified the areas of existing landslide location (Bui et al., 2011). But the success rate is not able to assess the prediction capacity of the models because it included all training landslide pixels that have been already used for model building. Whereas prediction rate indicates how well the model and predictor variables predict the hazard potential (Bui et al., 2011). Kannan et al., (2013), Van Westen et al., 2003, used R-index or landslide index for validation for hazard zonation. It illustrates the performance of hazard classification.

2.7 Vulnerability

The vulnerability is generally defined as the characteristics and circumstances of a community, system or properties that make it susceptible to the damaging effects of a hazard. Vulnerability assessments involve tools and processes used to assess the vulnerability of a community and its natural resources to climate change and such approach covers three main areas: exposure, sensitivity, and adaptive capacity, as they collectively regulate the level of vulnerability to climate change impacts (Marshall et al., 2010, USAID 2009, Turner, 2003). The vulnerability is an essential part of the assessment of landslide hazard (Leone et al., 1996). Vulnerability evaluation includes the comprehension of the collaboration between a given landslide and the affected parameters. By and large, the vulnerability of landslide may rely on upon (a) run out distance; (b) the volume and speed of sliding; (c) the components at risk (building and different structures), their tendency and their nearness to the slide; and (d) the components at risk (people), their vicinity to the slide, the nature of the building/street that they are in, and where they are in the working, out and about, and so forth (Finlay, 1996).
The quantitative assessment of vulnerability in the context of hazard and risk analysis has grown in importance due to global environmental change impacts, as well as social and economic changes. Landslide consequences are underestimated in many parts of the world, where transportation networks, buildings, essential facilities, and lifelines are severely damaged by mass failures and associated processes, yet the knowledge about the exposure to different types of landslide processes, the quality and quantity of the elements at risk and the relation between the landslide damage potential and the susceptibility to loss of the threatening objects or systems is limited. The appraisal of vulnerability is fairly subjective and to a great extent based on historic or topographic wetness records. The vulnerability of lives and property to landslide might be distinctive. For example, a house may have a comparable and high vulnerability to a moderate moving and a fast landslide, yet people living in the property may have a low vulnerability to the moderate moving landslide, however, a higher vulnerability to the quick landslide (Fell, 1994; Fell and Hartford, 1997). Coping capacities is defined in which people, community or organizations practice available resources and capabilities to aspect adverse magnitudes that could lead to a disaster (UN/ISDR, 2004). Given a specific facility class and the probable depth of debris at the location, the suitable vulnerability element might be surveyed efficiently by expert judgment. Another technique for surveying the vulnerability of an individual as well as property to landslide depends on the statistics measurements of detailed historical records. There are many aspects of vulnerability such as physical, demographic, social-economic, and policy indicators.

![Sustainable Livelihood Framework](source: Baas, et al., 2008.)
2.7.1 Physical Vulnerability

The term physical vulnerability represents the degree of loss of an element to suffer damage from external pressure, specifically from natural phenomena, of a given intensity (Canuti et al., 1999). The physical vulnerability is a key parameter in risk estimation and defines the level of damage given that the hazard is realized, and hence translates hazard levels into risk levels. The physical vulnerability is considered to be a spatial phenomenon that is possible to compute or model. This means that geographical aspects such as location, spatial extent, and spatial relationships are considered to be related to the physical vulnerability because both the systems and hazards have spatial characteristics that affect the level of susceptibility and the possible severity of the impacts (Karlson, 2012). The physical vulnerability is a function of the intensity and magnitude of the hazard, the degree of physical protection provided by the natural and built environment, and/or the resistance levels of the exposed elements (Corominas et al., 2013; Li et al., 2010). Physical factors encompass the aspects of location and susceptibilities of the built environment which refers to the susceptibility of individuals, households, and communities to their physical environment with aspect to access to suitable land, land use planning, housing design, building standards, materials used for building houses, accessibility to emergency services. It also involves remotely located settlements, lack of access to service infrastructure and information (Wisner, et al., 2004).

2.7.2 Demographic Vulnerability

Generally for the demographic vulnerability, household composition which comprises of age, single parenting, and disability variables are taken for account. Household composition is defined here to include dependent children less than 18 years of age, people aged 65 years and older and single-parent households. Also included are people with disabilities. People in any of these categories are likelier to require financial support, transportation, medical care, or assistance with ordinary daily activities during disasters. Women, children, and elders are the most vulnerable groups in disaster events (Cutter et al., 2003; Hinotoli and Balamurugan, 2017). Children, especially in the youngest age groups, cannot protect themselves during a disaster because they lack the necessary resources, knowledge, or life experiences to effectively cope with the situation. Maybe if parental takes responsibility to accept the children as children are hardly integrated into disaster situation training. Hence, special needs and services are missed out or are not adequately prepared by any decision makers and senior citizen living alone and people of any age having some challenges such as physical, sensory,
or mentally is also likely to be more vulnerable to any disaster (Schmidlin and King 1995; Elliot and Pais, 2006; Madrid et al., 2006; Martin et al., 2006; White et al., 2006; Morrow 1999; Rosenkoetter et al., 2007).

2.8 Risk Analysis

The risk is a substantial method if and, in the event, that it satisfies a progression of suitable measures taking in considerations of hazard and vulnerability in connection to the population's measure at risk. Varnes (1984), and Fell (1994), studies identified with risk investigation where risk is generally considered as a function of three components: hazard, the actual event of concern, whether it be natural (e.g. earthquakes), anthropogenic (e.g. industrial accident) or a combination of the two (e.g. the Fukushima nuclear disaster); vulnerability, meaning how susceptible a population, asset or structure is to the loading imposed upon it by the hazardous event, and the theme of this work, exposure (Pittore, et al., 2016). Risk refers to the compilation of all the elements such as people, property, systems, societal functions, the economy, traditional and cultural heritage and the environment present in hazard zones that are potentially subject to losses (UNISDR 2009), where a given element may be exposed to one or more hazards. It considers the probability of risky magnitudes or expected losses such as deaths, injuries, property, livelihoods, economic activity disrupted or environmentally damaged which results from interactions between natural or human-induced hazards and vulnerable conditions. Risk can be calculated using the following equation:

\[ \text{Risk} = \text{Probability of Hazard} \times \text{Degree of Vulnerability} \]  
\[ \text{................. (Eq.3)} \]

2.9 Previous works in Nagaland

Landslide is a common and serious geohazards in Nagaland, yet the contributions to the study of landslides in Nagaland are very limited. The first ever attempt of landslide studies was conducted by Sondhi (1941) along the Dimapur-Manipur road. Sharda and Bhambay (1980) prepared geotechnical and slope classification maps of Kohima Town. They also conducted environmental and geotechnical/geoscientific studies of the same area. Anand (1988) conducted preliminary geological investigations of landslides along the Dimapur-Mao section. Sarmah (1989) investigated the clay minerals of the Disang and Barail Groups of sediments. A study of the feasibility of groundwater development in and around Kohima

According to Central Road Research Institute (2000b), Nagaland is a geologically unstable area where hill slopes are subjected to subsidence, upheaval, aggravated by frequent tremor, causing large-scale landslide, since it falls in seismically active zone V. There are many causes of landslides where quarrying is the major factor and others such as complex tectonic-geological set-up, high degree of relief, high intensity of precipitation, land use, cultivation such as shifting cultivation (jhum) and heavy tilling agricultural practices.

Aier et al., (2005) investigated the Lalmati slide to provide mitigation measures. Walling et al., (2005) suggested mitigation measures for the Chiefpufsiepfe slide of Kohima. The Directorate of Geology and Mining (2005) investigated landslides that occurred on 25th June 2005 in Mokokchung town. Aier (2005) is of the opinion that lithology, structure, and drainage are the most important controls of slope characteristics. An estimated 80 percent of landslides have occurred on slopes greater than 30° and hence giving higher chances of occurrences of debris flow at that degree of slope. Aier and Thong (2006) reported on the major subsidence at the Lumami Campus of the Nagaland University, Zunheboto. Thong et al., (2006a) and Thong et al., (2006b) submitted detailed project reports on their investigations of land instability along part of the NH 39 and Kohima town. Thong et al., (2007) reported on the 179 km slide along the NH 39. Aier et al., (2009b) gave a detailed account of SMR and kinematic analyses along part of NH 61, Nagaland. Landslides incidences are closely associated with slope inclination. Thickly bedded but untenable, weathered friable and loose sediments of shale, unconsolidated soil sediments are observed to
be solely responsible for the course of heavy landslides in such a high mobile seismic zone of highly trusted hilly terrain of Zunheboto Town (DGM, 2009). Aier et al., (2011b) investigated instability at Para Medical Colony (Merhülietsa) of Kohima town. Supongtemjen (2006) has done case studies on Geological investigation of land instability between Kohima and Zhadima.