# A MULTI-CRITERION APPROACH FOR LANDSLIDE SUSCEPTIBILITY MAPPING USING ANALYTICAL HIERARCHY PROCESS: A CASE STUDY IN MANIPUR, INDIA

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## ABSTRACT

Landslides are one of the major natural hazards accounting each year for enormous economic loss and loss of life. The probability of landslides is highest along mountain roads that causes hurdles in traffics and also cause congestion. A landslide susceptibility map presents areas with the potential of landslides in the future by combining factors that contributed to the occurrences of past landslides. The aim of this study is to evaluate the susceptibility of landslide along a highway passing through Noney area, Manipur, India with respect to identified factors that influence the occurrence of landslides such as slope, land use land cover (LULC), Normalized Difference Vegetation Index (NDVI), Normalized Difference Mid Red (NDMIDR) index, Normalized Difference Mid Infra-red (NDMIDIR) index and Geology. Geographical Information System (GIS) based Analytical Hierarchy Process (AHP) is adopted for the landslide susceptibility mapping of the region. A landslide inventory of 43 landslides was created using past landslide records collected from field investigations. Analyzing the past landslides record and influencing factors, the importance of each parameters were determined and weightage were assigned based on AHP for generating the susceptibility zone map. The landslide susceptibility map was compared with the landslide occurrence locations as an approach to check the accuracy of the model output. The overlay of the known landslide locations with the susceptibility map revealed that the output maps are in good agreement with the landslide locations as 48.83% of the landslide locations fall under the very high susceptible zone; 27.91% and 23.25% falls under high and moderate susceptible zones respectively.

## 1. INTRODUCTION:

Landslide is a very common phenomenon occurring in most of the hilly terrain having unstable slope and having weak and fragile lithology. The damage caused by this natural hazard is enormous. It has caused the loss of many lives and property all over the world which has affected the economic condition to a large extent. On an average, landslides are responsible for 17% of all fatalities from natural hazards worldwide (CRED, 2006). The study of landslides is becoming a topic of interest for many researchers, geoscientists and engineers. In order to reduce the losses and for safety, many approaches have been developed all over the world for mapping past landslides occurrences. Remote sensing and GIS techniques have proved to very useful in the study of landslides.

Landslides are part of geomorphic surface process affecting terrains at different climatic conditions causing damages to life and property and producing negative impacts on the natural environment (Alimohammadlou et al., 2013). Mountains roads are most susceptible to landslides causing hurdles to traffic and economic losses. Detailed inventories do exist which contains information of past landslides but in areas where no such information exists, the inhabitants are exposed to risks of unstable slopes (Taherynia, M. H et al., 2014). It is very important to map landslide susceptibility zones as the probability of recurring landslides is very high under similar conditions (Guzzetti et al., 2012). But, sometimes landslides can occur in areas where there is no history of past occurrences due to several anthropogenic activities, changes in topography and or hydrologic conditions (Highland et al., 2008). Mapping landslide affected area can be a safety measure (Pradhan and Lee, 2006).

Landslide susceptibility is the likelihood of a landslide occurring in an area on the basis of local terrain conditions (Brabb, 1984). A landslide susceptibility map presents areas with the potential of landslides in the future by combining factors that contributed to the occurrences of past landslides. This map can be valuable tool for assessing and predicting the current and potential risks that can be very useful for developing early warning systems and for mitigation plans like selecting suitable site for constructions of roads and buildings, etc. So proper planning can help in decreasing the damage caused by land sliding and it will also prevent from heavy economic losses.

Landslide susceptibility can be determined by a wide range of techniques that can be geomorphic mapping, stability analysis or expert opinion. The applied model in this study is the Analytical Hierarchy Process (AHP) approach.

The Analytical Hierarchy Process (AHP) is a multi-criteria decision making process of measurement through pair wise comparisons and to derive priority scales. It is a tool used in analyzing complicated problems which focuses on site selection, urban planning and landslide susceptibility analysis (Satty 2008). Some studies carried out on landslide susceptibility zonation using AHP are as follows- Himam Shahabi et al (2014), P. Kayastha et al (2013), Omar F. Althuwaynee et al (2016), Ali Yalcin et al (2008), Ayalew et al (2005).

The main aim of this study was to develop a landslide susceptibility zonation map, showing a subdivision of the terrain in zones that have a different spatial likelihood of landslide to occur, along a National Highway in a sub-district in Manipur, India using factors contributing to landslide occurrence such as topographic slope, geological factor, land use land cover (LULC), past and recent landslide locations and various spectral vegetation indices maps.

## 2. REMOTE SENSING IN LANDSLIDE MAPPING:

Landslides are regarded as localized phenomena which reflect site specific stability conditions in which vegetation cover contributes to root cohesion thus influencing slope stability (Roering J.J. et al., 2003; Schmidt et al., 2001). Anthropogenic activities like forest clearing can also increase the number of occurrence of landslides (Sidle et al., 1985; Kurupuarachchi et al., 1992). Thus, applications involving landsliding or risk mapping require the identification of disturbed vegetation or land degradation, which are then related to landslide occurrences.

Vegetation spectral indices take major role in the classification of landslide areas. Various indices were used in the classification of landslides scars and non-vegetated areas (M.W. Mwaniki et al., 2015). Normalized Difference Vegetation Index (NDVI) has been used as an indicator of vegetation greenness but it responds to both soil as well as vegetation greenness (Ardavan et al., 2012; Govaerts et al., 2010). High values of NDVI correspond to areas of high greenness and low NDVI values correspond to high wetness areas and moderate values correspond to areas of high brightness.

Landsat imagery has major applications in developing spectral indices (Daughtry et al., 2004). Landsat bands 7 and 4 have been used to develop Normalized Difference Mid Infra Red (NDMIDIR) Index which can be used to identify landslide scars and forest fire scars (Vohora et al., 2004).

$$\text{NDVI}=\frac{TM5-TM4}{TM5+TM4} \quad (1)$$

$$\text{NDMIDIR}=\frac{TM7-TM4}{TM7+TM4} \quad (2)$$

where TM stands for Landsat Thematic Mapper.

Other spectral index, Normalized Difference Mid Red (NDMIDR) Index was also used in the mapping of landslide zones. These spectral indices have earlier been used in the classification of landslides (Mwaniki et al., 2015).

$$\text{NDMIDR}=\frac{TM7-TM3}{TM7+TM3} \quad (3)$$

This spectral index is modified from NDMIDIR developed by Vohora and Donoghue (2004).

## 3. METHODOLOGY:

### 3.1. STUDY AREA:

Manipur is a landlocked hilly state lying to the north eastern border of India. It has a total area of 22327 sq. kms. Geographically, the State of Manipur could be divided into two regions, viz. the hill and the valley. The average elevation of the valley is about 790 m above the sea level and that of the hills is between 1500 m and 1800m. Among these, 90 % constitute the hilly regions. The hill districts of Manipur i.e. Chandel, Tamenglong, Churachandpur, Ukhrul, Senapati are highly vulnerable to landslides.

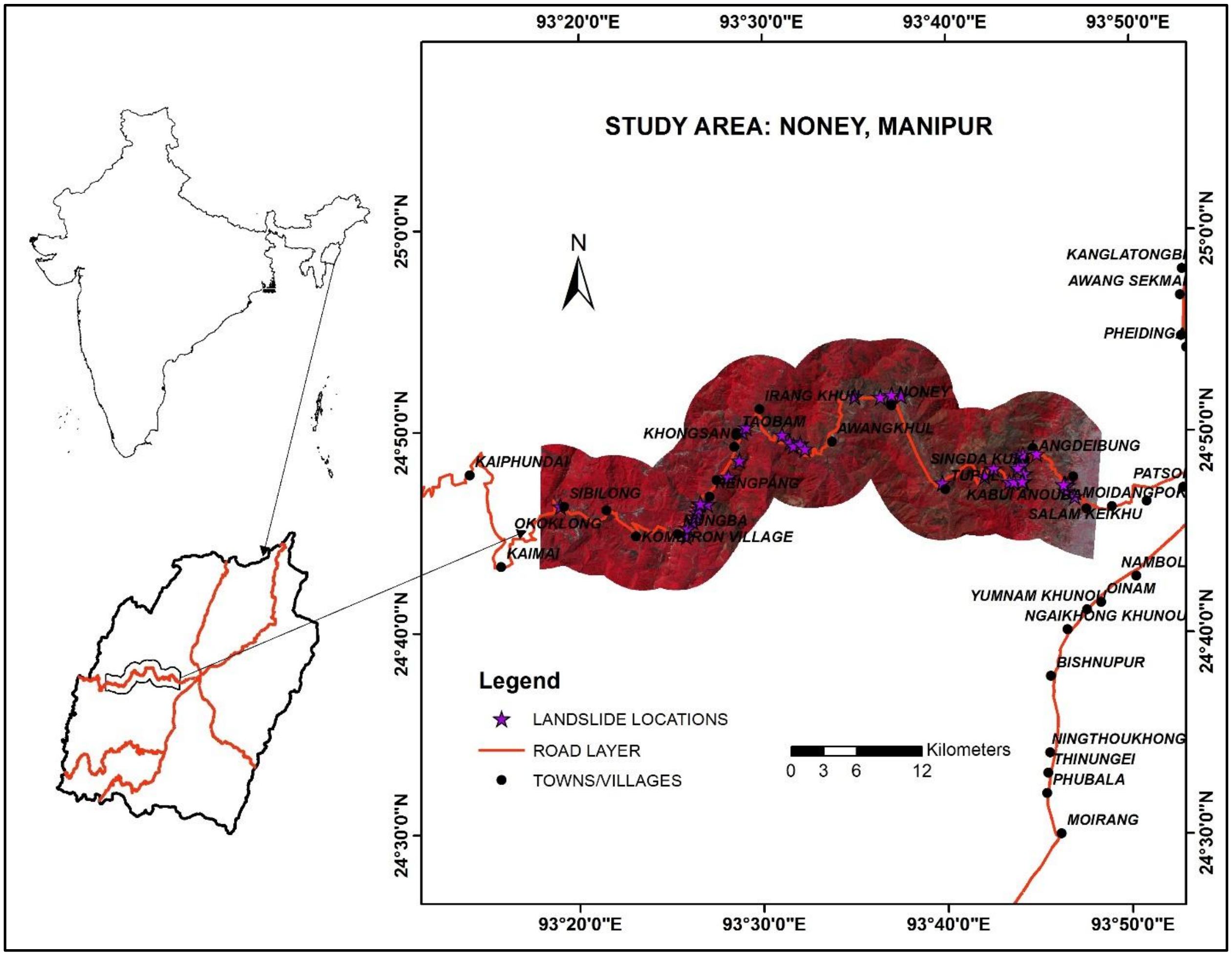

FIGURE 1: STUDY AREA, NONEY, MANIPUR

National highway 37 in Tamenglong district is served as one of the lifelines of this landlocked state connecting the state with Assam and this highway is often blocked by landslides during the rainy seasons. Due to heavy rainfall, weak and fragile lithology coupled with anthropogenic factors and improper planning and drainages, this area along the highway is highly susceptible to landslides. A buffer of 5 km on both sides of the NH-37 covering an area of 708 sq km has been considered and an effort has been made to prepare landslide susceptibility zonation map of the area.

Some of the recent major landslides witnessed in the area are the May 24, 2016 landslide on Tamenglong-Khonsang road, in which half of the road surface near Awangkhul have been damaged; the July1, 2017 landslide in the Charoi-pandongba village; July 9, 2017 landslide which damaged around 60ft of the NH 37 between Sinam and Laijing village; and the July 17 landslide which have damaged a bridge over the Barak river.

In Manipur, landslides are quiet frequent and past records show that landslides mostly occur during the rainy seasons in the month of June to September. Landslide study using analytical techniques in a northeastern state of India like Manipur would be difficult task due to lack of historical data which may be required during the study for validation purposes.

In general, the causes of landslides in Manipur are mainly due to weak lithology consisting of intense structural features like highly jointed formation and fractures; unstable and steep slope and high rainfall during the rainy seasons. Above that Manipur has geologically young formation and lie in the geodynamically active domain of the Himalaya, earthquakes and intensive soil erosions trigger landslides in the area. Others factors include anthropogenic activities like excessive land use, deforestation, wild firing for performing cultivation, excavation of slope, quarrying and other heavy constructions on the unstable terrain causing slope instability thus triggering landslides. The damage caused by landslides is increasing due to improper planning and thus nowadays many researchers and organizations are showing their interests in landslide studies to reduce the damage both socially and economically.

### 3.2. DATA DESCRIPTION:

Nearly cloud free Landsat TM (2017) Level 1 images i.e., p135r42 and p135r43 were downloaded from USGS webpage. Mosiacking and subsetting was done in GIS environment in order to extract the area of interest (AOI). A boundary shapefile has been created from Census Atlas Map of India (2011) for extracting the AOI. And ASTER DEM data of 30m resolution has been used to generate slope of the area. Road layers (highways) shapefile has been created from Census Atlas Map of India (2011). Landslides locations of past field visits collected from Earth Science Department, Manipur University, MASTEC and landslides locations taken during reconnaissance field survey during the month of April were used for validation of the model result.

### 3.3. METHODS:

Radiometric correction is done to reduce errors in the digital numbers of images and is done by converting DN values to surface reflectance values for all images. Calculation of the vegetation indices was done in GIS environment. A land use land cover (LULC) map has been prepared from the satellite imaging by using the algorithm of spectral angle mapping.

Accuracy assessment of the output LULC map was done to know the accuracy of the resulting map and this in turn has been used as a zoned map for finding the threshold values of the spectral indices and reclassification of the layers have been done. These reclassified layers have been assigned different weights and AHP was used to produce the landslide susceptibility map. Overlay of the landslide susceptibility map with the known landslide locations has been done for validation of the resulting landslide susceptibility map.

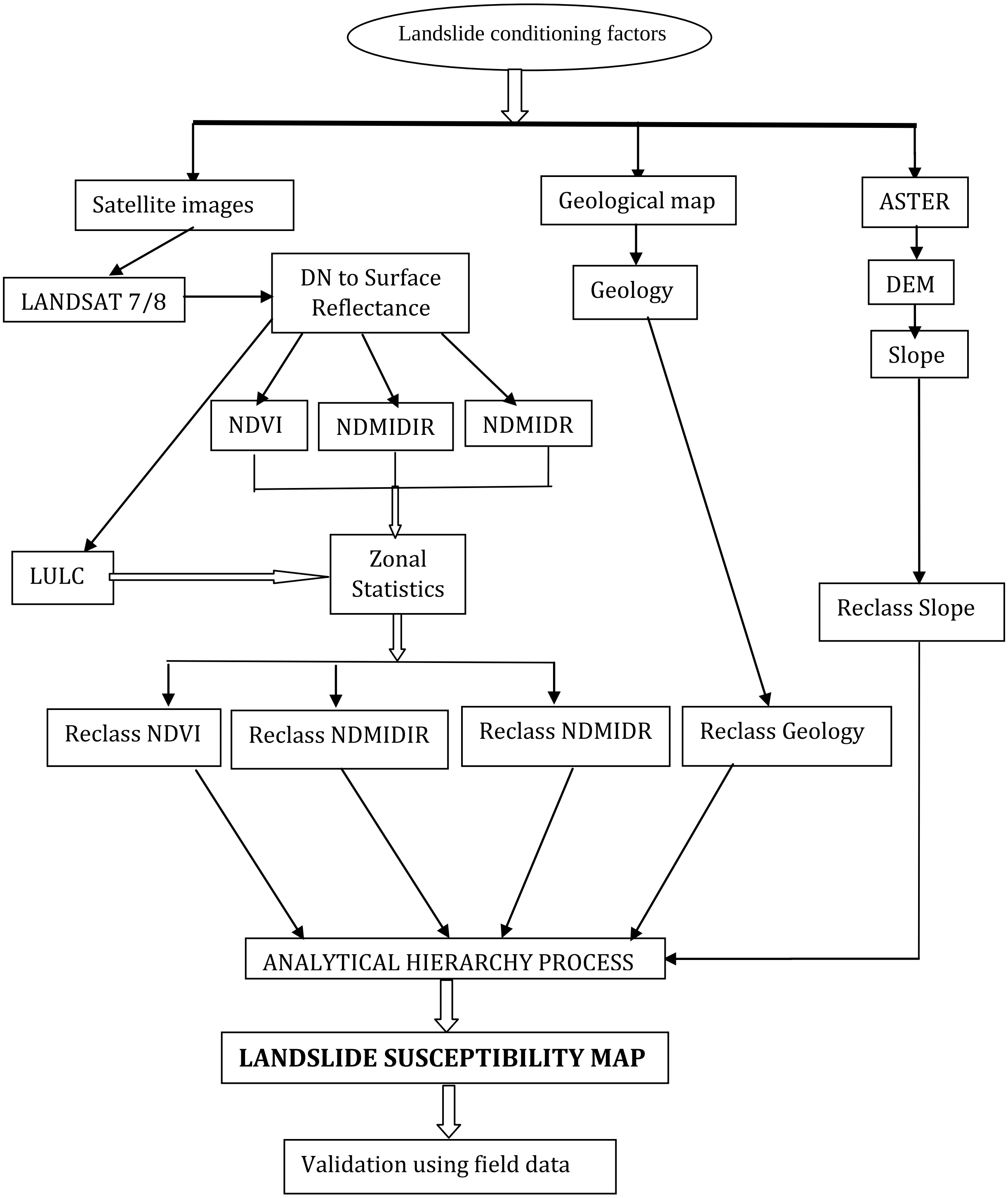

FIGURE 2: FLOWCHART SHOWING METHODOLOGY

## 4. RESULTS AND DISCUSSIONS:

Supervised classification has been done for the Landsat imagery to find out the LULC of the study area using the algorithm of Spectral Angle Mapper (SAM) in QGIS platform. Accuracy assessment of the output LULC map revealed that it has a high accuracy with a kappa value of 0.83. The use of spectral layer like NDMIDR, involving bands 7 and 3, emphasized more on the moisture content in vegetation and soils. It is due to the use of SWIR band 7, which is a band sensitive to canopy moisture content (Vohora and Donoghue, 2004). This spectral index outperformed NDVI as it emphasized only on the vegetated areas and provided fewer details about texture (Mercy Mwaniki et al. 2015). The landslide triggering factors have been extracted from various database using ASTER DEM database and Landsat 8 satellite imageries. The landslide susceptibility analysis has been performed using the GIS based statistical model, AHP.

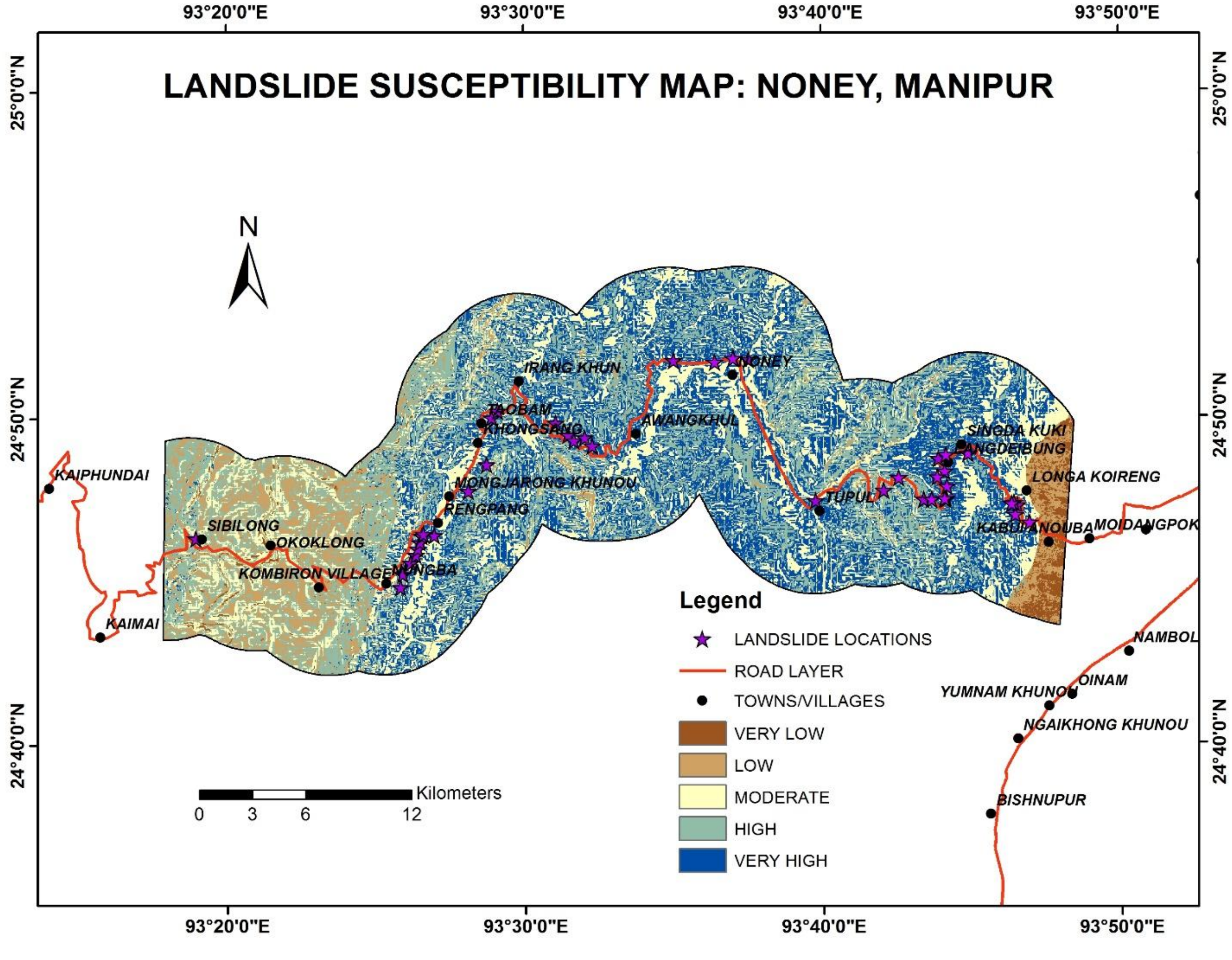

FIGURE 3: LANDSLIDE SUSCEPTIBILITY MAP

FIGURE 4: LANDSLIDE LOCATIONS COLLECTED DURING FIELD SURVEY

**Landslide susceptibility mapping using AHP model:** The rating values for each influencing factors has been calculated based on previous literature and the importance of each influencing factors has been found out. Weights have been assigned for each and every factor considering the importance. The consistency ratio has been found out to be 0.087 and is a reasonable level of consistency since it is less than 0.1. The resulting landslide susceptibility map was again divided into 5 zones of susceptibility as very low, low, moderate, high and very high susceptibility zones based on the natural breaks method.

According to the landslide susceptibility map acquired from AHP, only 10% of the study area falls under the very low landslide susceptibility zone, low, moderate, high and very high susceptible zones have shown 10.5, 23.12%, 25.9 % and 31.2 % respectively.

Overlay of the output resulting susceptibility map from AHP and the known landslide locations collected from field surveys revealed that 48.83% of the landslides fall in the zones of high susceptibility, 27.91% under high susceptibility zone and 23.25% falls under the moderate susceptibility zone.

## 5. CONCLUSION:

Due to the cloudy weather and high vegetation, the landslide susceptibility mapping in the tropical regions are usually difficult. In the present study, AHP approach has been used to map the landslide susceptibility zones along a major highway of the state of Manipur, India. A landslide inventory of 43 landslides has been used in the validation of the output susceptibility map. Six conditioning factors as slope, geology, NDMIDIR, NDVI, NDMIDIR and LULC have been considered. The selected causative factors have been observed carefully and weights were assigned accordingly. However due to lack of data, only few existing data have been considered. Therefore more accurate landslide susceptibility mapping can be done using precipitation data and soil information. The validation result shows acceptable agreement relating to the susceptibility map and the landslide locations. The output map can be used by planners for future projects and construction purposes.

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