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GIS Based Bi-variate Statistical Approach for Landslide Susceptibility Mapping of South District, Sikkim

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ABSTRACT: Geologically diverse, Sikkim Himalaya is one of the vulnerable zones in terms of natural hazards. Being in Earthquake zone-IV and high rainfall area, the South districtis considered as one of the landslide susceptible zones of the state. The study is based on the Geo-statistical approach by using geospatial data analysis in ArcGIS software for landslide susceptibility mapping. The important factors for landslide susceptibility had been identified and thethematic mapswere prepared in GIS. Various datasets like satellite image, topographic maps and some published maps were used to generate these thematic layers. The numerical valueswere calculated from the thematic layers by using information value model. A landslide susceptibility map of the study area hadbeen generated by integrating all the layers in GIS (Geographic Information System) environment. Five categories of landslide susceptible zones in a part of South Sikkim have been generated i.e. very high, high, moderate, low and very low. This output result has been validated by reported landslide events and by using field survey of the study area.

KEYWORDS: Landslide susceptibility, Bi-variate statistics, Information value model (IVM), GIS, Sikkim.

I. INTRODUCTION

Sikkim is a part of Eastern Himalayas, and theentire state is hilly with an elevation range of 230 to 8583 meters.Landslide occurrences are very common in the Sikkim Himalayas causing lots of damages due to calamities every year(Bhasin et al., 2002). Due to its hydro-meteorological condition, Sikkim is the highest rainfall zone in India and receives more than 2500mm rainfall. Rainfall is the major triggering factor for landslide. Along with this, there are some other factors which make the state more prone towards themass movement. The steep slope, earthquakes and ruggedness are also some major factors for landslide occurrence in Sikkim. The landslide in Sikkim is not only due to natural phenomenon, but it is also due to anthropogenic activities like road cutting, deforestation etc. (Gupta et al., 2009).

The state is divided into four districts i.e. East, West, North and South. The area under investigation was South district. It is surrounded by two major rivers Teesta and Ranjit which flow from north to south direction. Namchi is the headquarter of South district and due to its natural beauty, it is developing rapidly. Due to population and tourism pressure, the construction of roads and buildings are going on, and as a result, the hilly slopes are getting disturbed day by day (Sarkar et al., 2008). The intense rainfall in the study area trigger the slope failure mainly in monsoon season and causes debris slide, rock slide and earth creep. It is found that 90% of losses due to landslide can be ignored if the probability of occurrence is known before the landslide occurrence (Pardeshi et al., 2013). Therefore, it is needed to characterize the responsible factors contributing for landslide and provide an informative landslide susceptible map for policy makers. This study will be helpful before starting any new developmental project.

The probability of landslide occurrence mainly depends upon the instability of the slopes and the triggering factors play very important role for the instability. These factors grouped into two categories: 1. The Preparatory variables 2. The



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triggering variables. In simple language, the preparatory variables prepare the condition to make the slope susceptible to failure without actually initiating this process. The factors like geology, landuse landcover (LULC), slope, elevation, aspect, distance to drainage, distance to fault, vegetation cover etc. comes under preparatory variables. The triggering factors are those which shift the slope from a stable to unstable condition and initiate the failure of thesusceptiblearea and these are heavy rainfall and earthquakes. With this discussion, it is clear that both the variables are responsible for landslide occurrences. In this study, only preparatory factors have been taken into account and hence the susceptibility map was prepared which define the possibility of occurrence of landslide events (Dai, 2002). Various methods have been used todelineate the landslide susceptible zoneand plenty of research papers are published for this work. The heuristic approach, inventory based mapping, probabilistic assessment, deterministic approach, statistical analysis and multi-criteriadecision-making approachand many methods had been developed for landslide hazard zonation (LHZ) mapping (Pardeshi et al., 2013). Nowadays the statistical approach is preferably used in various research papers. This method is grouped under two category 1. Bivariate statistical analysis and 2. Multivariate statistical analysis. The bivariate statistical approach is used for landslide susceptibility zonation based on theinfluence of each variable on the occurrence of landslide and the variables are combined by a unique equation (Nandi et al., 2010). There are various methods used for bivariate statistical approach i.e. information value model (IVM), frequency analysis approach, weights of evidence model, weighted overlay model etc. (Pardeshi et al., 2013). The information value model is preferably used due to its statistical and numerical approach in the study area. The present study had been done in geographic information system (GIS) environment. Various thematic raster layers of all corresponding factors were generated and analyzed in GIS environment for landslide susceptibility mapping of South Sikkim. The susceptibility map had classified into five categories i.e. very high, high, moderate, low and very low susceptible zones of landslides.

II. STUDY AREA

Sikkim is the second smallest state of India having ageographical area of about 7096 sq. km (Map of India, 2017; State report). It is bounded by latitude 27° 04' N to 28° 07' N and longitude 88° 0' E to 88° 55' E and it shares an international border with three countries China, Bhutan and Nepal and in thesouth it touches the border of West Bengal in India (Figure 1). The present study focused on the part of South District of Sikkimwhich shares the state boundaries with North, West and East districts of the state itself and in thesouth it touches the border of West Bengal. The Headquarter of South district is Namchi which is 78 km away from the capital of Sikkim. Area-wise, South Sikkim is the smallest district of Sikkim which is about 750 sq. km while population-wise it comes at thesecondposition. According to IMD, whole state is come under earthquake zone IV. The annual average rainfall in South Sikkim is 1625 mm and the maximum temperature varies from 17 to $27 \Box$ C while minimum temperature varies from 02 to $21 \Box$ C. This variation in temperature can be seen due to variation in altitude and it varies from 400 m to 2000 m.



Fig.1Figure showing theLocation map of South Sikkim



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III. MATERIAL AND METHODS

3.1 Satellite data:

 Table 1:List of satellite data used in this study

Years	Satellite	Sensor	Resolution	Data acquisition date	WRS Path/row
1997	Landsat 5	ТМ	30 m	07/10/1997	139/41
2000	Landsat 7	ETM+	30 m	26/09/2000	139/41
2005	Landsat 5	ТМ	30 m	13/10/2005	139/41
2008	Landsat 5	ТМ	30 m	21/10/2008	139/41

• Shuttle Radar Topographic Mission (SRTM) DEM (Digital Elevation Model) data, 30m Resolution

3.2 Software used:

- ERDAS Imagine 9.1 used to preprocess the satellite data
- ArcGIS 9.3 for generation of thematic layers and Susceptibility map generation

3.3 Ancillary data:

• 1:50000 scale Survey of India (SOI) topographic sheet no. 78A6, 78A7 and 78A8 used to georectification of Satellite data



Figure. 2 Flow chart of Landslide susceptibility map zonation methodology

The Raster layers of all the responsible factors were generated using ArcGIS software. After generation of these layers, numerical weightagewas assigned on the basis of their importance for landslide occurrence. There are various ways available to assign the weightage to the responsible factors. One is to assign the weights to all the responsible factors based on literature review and expertise about the subject and area. The weights for the relative factors may vary from expert to expert and also from area to area (Karungo et al., 2009). The second one is based on a statistical approach where the weightage is derived from a numerical calculation based on the landslide occurrence in the field. The assigning of weights to each thematic layers and their respective categories was the major limitation of this approach.



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Therefore the statistical approach was used in this study. The bivariate statistical approach was applied where the numerical values were calculated using Information value model.

This information value was based on the relationship between the landslide occurrence and related parameters. After calculation of numerical values for all the causative factors, the raster layers with the numerical values were generated. After integration of all the layers into GIS environment, a landslide susceptible map was prepared. The flowchart of the methodology was shown in Figure 2.

IV. RESULTS AND DISCUSSION

The landslide susceptibility zonation map were prepared from various spatial data layers. These layers were integrated into GIS environment using bivariate statistical technique. The landslide susceptible zones were generated and validate by field data.

4.1 Spatial data layers:

4.1.1 Landslide inventory maps

The study of landslide hazard primarily focuses on landslide inventory because these inventories are very important for most of the landslide susceptibility mapping techniques. It can be prepared by collecting the information from historical events of landslides or aerial photographs followed by field checking (Dai, 2002). There were various sites present in the study area where the landslide occurrence wasseen. Out of these sites, 17 sitesare reported by Sikkim State Disaster Management Authority in Inventory and GIS mapping of Landslide in North, East, West and South Sikkim and its Mitigation, 2007. These pointswere used for validation of landslide susceptibility map. The aerial photographs play very significant role in theidentification of landslide area (Guzzetti et al., 2012). The satellite images of four different years were selected for the identification of areas of landslide occurrences which depends upon the reflectance of the area (Table 1). The identification of landslide areas also helped in the visual identification. Due to slides, the vegetation cover gets destroyed exposing the surface. This region shows high reflectance in the image and the irregular shape confirms the landslide events (Karungo et al., 2009). With the help of ArcGIS software, the inventory map had been generated and 34 landslide spots were identified from all the satellite images (Table 2).

The landslide events depend upon basically two types of factors one is preparatory factors and other is triggering factors. Triggering factors involves to initiate the landslide while the preparatory factors only inform about the susceptibility of landslide occurrence. In this study, most of the preparatory factors were collected from various sources such as reports, satellite data, topographic map and DEM data. Nine factors were used to generate landslide susceptible map of South Sikkim. These factors are LULC, lithology, slope, elevation, aspect, fault buffer, drainage buffer, road buffer and NDVI map. The raster layer of all these causative factors was prepared in GIS.



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Table 2:List of identified landslide spot collected from different year of satellite images.

SN	Year	Latitude	Longitude	Area (m2)	SN	Year	Latitude	Longitude	Area(m2)
1	2008	27.33	88.42	63498.70	18	1997	27.36	88.46	28665.00
2	2008	27.33	88.45	70427.30	19	1997	27.38	88.44	12645.20
3	2008	27.32	88.40	347153.00	20	2000	27.11	88.44	373426.00
4	2008	27.31	88.42	67798.90	21	2000	27.41	88.35	30396.00
5	2008	27.31	88.43	47917.90	22	2000	27.42	88.37	33073.00
6	2008	27.31	88.31	21023.70	23	2000	27.38	88.41	26179.90
7	2008	27.29	88.34	47891.20	24	2000	27.13	88.39	34823.70
8	2008	27.29	88.45	61060.00	25	1997	27.41	88.38	95767.90
9	2008	27.28	88.41	55434.70	26	1997	27.35	88.43	34322.60
10	2008	27.27	88.31	95125.30	27	2005	27.33	88.45	147252.00
11	2008	27.21	88.44	54150.40	28	2005	27.33	88.45	127433.00
12	2008	27.16	88.51	52799.30	29	1997	27.35	88.44	43765.20
13	2008	27.15	88.51	62265.70	30	2008	27.38	88.44	33315.50
14	2008	27.13	88.50	22219.00	31	2000	27.35	88.45	90306.00
15	2008	27.14	88.48	365929.00	32	2000	27.41	88.36	35156.30
16	1997	27.11	88.40	176921.00	33	2000	27.44	88.39	30394.30
17	1997	27.36	88.46	26629.20	34	2008	27.23	88.43	17858.20

4.1.2 Lithology

The geological information was collected from the report of Geology and Mineral Resource of Sikkim, Geological Survey of India, 2012. First of all the geology map was geo-rectified using ERDAS Imagine software. This geo-rectified image was brought into GIS environment and the whole image was then digitized and saved as vector file. The geology of South Sikkim shows that most of the region is dominated by Gorubathan formation followed by Kanchenjunga Gneiss, Reyong formation and Damuda group. Many other formations were also identified in less dominant form. Chlorite, Schist, Phyllite, quartzite were dominant in most of the part of the study area, whereas the northern part which is usually covered with glaciers were dominated by Kyanite, Biotite, Mica Schist etc. Phyllite, Dolostone and cherty Phyllite were dominated towards the western side of the study area. Sandstone, phyllite and chlorite schist rocks were found more prone to landslides.

4.1.3 Land use/land cover (LULC)

The LULC map was prepared using remote sensing data. Landsat 5, Thematic Mapper image was layer stacked and subset into ERDAS Imagine 9.1 software. After that, the unsupervised classification was carried out using K-mean classifier method (Vishwakarma et al., 2016). By spectral signature, the image had been classified into seven major classes. These were Forest, Scrubland, Waterbodies, Agricultural land, Built up area, Glacier and Barren land. Forest majorly covered the study area. The forest, agricultural land and scrubland did not affect much on landslide occurrence. Whereas the built up area and barren land were more prone to landslide event.



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Figure. 3 (a) Landslide inventory map of study area generated from the multitemporal satellite datasets (b) The lithology map of south sikkim collected from Geological survery of India (c) Landuse/landcover of South Sikkim with seven major classes.

4.1.4 Normalized difference vegetation index (NDVI):

Normalized difference vegetation index (NDVI) is a most widely used index for monitoring green cover from remote sensing images. It is calculated using two wavelengths i.e. Red and Near-infrared (NIR). It is the ratio of the difference of near infrared (NIR) and red bands by their addition which gives the effective measurement of photosynthetic biomass (Huete et al., 1997; Singh et al., 2016). The chlorophyll pigment in plant leaves strongly absorbs visible light (from 0.4 to 0.7 μ m) for photosynthesis. On the other hand, the cell structure of the leaves strongly reflects near-infrared light (from 0.7 to 1.1 μ m) (Earth Observatory, 2016). Therefore, these two bands are very useful to estimate the vegetation health.

Normalized difference vegetation index (NDVI) =
$$\frac{NIR-Red}{NIR+Red}$$
 (1)

NDVI ranges from -1 to +1. This value shows the vegetation health. Higher the NDVI value indicate healthier vegetation whereas the lower value indicates the sparse or unhealthy vegetation (Singh et al., 2016).

In the study area, the NDVI value ranges from -0.40 to 0.79. On the basis of these values, the image had been classified into three categories i.e. low, moderate and high NDVI (Humboldt State University, 2016). The low NDVI values were found in no vegetation zones like snow, rocky or barren areas. Sparse or less vegetation areas such as shrubs and



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grasslands showed low positive NDVI values which were placed in moderate NDVI category. And the high NDVI values correspond dense vegetation which was dominant in the study area.

4.1.5 Thrust and Normal Fault

The whole state of Sikkim belongs to some parts of Lesser Himalayas, Higher Himalayas and Tibetan Plateau. Main boundary thrust (MBT) passes through the southern part of West Bengal-Sikkim boundary. Main Central Thrust (MCT) passes through the central part of the state and normal fault passes through the northern part of the state. There are a number of small thrusts and NW and NE trending faults as well. Among them some faults still appear as active faults (GSI, 2012). Thrust and faults are a type of fractures in which horizontal or vertical displacement along the fault plane can range between few centimeters to thousands of kilometers (Crawford Mark J., 1998). In the present study the thrust and fault map was extracted from Geology and mineral map of GSI. It was digitized and converted as raster layer in GIS environment. The buffer zone map was created by taking a buffer distance of 1km, 2km, 3km, 4km, 5km and >5km. The areas near the fault and thrust lines were found out to be more prone to landslides. Some of the landslide events were even recorded away from the buffer zone. It was indicating the influence of some other factors as well.

4.1.6 Road buffer map

Since last two decades, rapid urbanization had occurred mainly due to economic growth as well as the migration of rural population towards the cities. Due to the hilly area, the urbanization had taken place linearly on main roads which connect the state to West Bengal (SAPCC, 2011). The transport and communication system plays a very important role in industrial development in the hilly region like Sikkim. Due to lack of rail network, transportation is mainly dependent on the road. There is only one highway i.e. National Highway-31A which is the main transport link between the state with the rest of the world. This highway connects the state capital Gangtok to Siliguri which is a major town of North Bengal. Other than the national highway, many state highways are also spread throughout the state which connects one district to other (State Industrial Profile of Sikkim, 2009)



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Figure 4 (a) Normalized Difference Vegetation Index (NDVI) after classification into High, Low and Moderate NDVI (b) Thrust Fault buffer map with buffer zone of 1km, 2km, 3km, 4km, 5km and more than 5km. (c) Road map of South Sikkim with buffer zone of 50m, 100m, 200m, 1000m and more than 1000m.

In this study, the road map was digitized using a topographic map. After getting the road map, the buffer map of the road network was generated in ArcGIS software. Various buffer distances were taken from the road having intervals 50m, 100m, 200m, 1000m and >1000m. During GIS analysis, it was found that the buffer zone which was closer to the road was more vulnerable than those which were far away from the road.

4.1.7 Digital elevation model (DEM) and its derivatives

Digital elevation model (DEM) is the representation of the regular array of elevation points (Chang,2014). Most of the GIS users prepare DEM of the study area using contour information given in the topographic map. There are other sources of DEM also such as satellite images, radar data and LIDAR (Light detection and ranging) data. In this study, Shuttle Radar Topographic Mission (SRTM) data with a resolution of 1arc-second (30 meters)was used. After preprocessing the images into GIS, slope, aspect, drainage and elevation mapswere generated. Drainage buffer was prepared using the drainage map.



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Figure 5 Derived images extracted from SRTM data. (a) Aspect map of South Sikkim (b) Extracted drainage map from a SRTM data with buffer zone of 50m, 100m and more than 100m. (c) Elevation map of South Sikkim in meter. (d) Slope map of South Sikkim in degree

The elevation ranges from 1012m to 5728m in the study area and it had been categorized into five classes. The study shows that the lowest elevated part of the study area was very much prone to landslide eventswhereas the elevation ranging from 2499m to 3552m was less prone. Aspect is the directional measure of the slope. The aspect mapwas prepared from hydrology tool of ArcGIS software. The slope direction towards north, north-east, south-west, west and north-west are less prone areas whereas those which lies in east, south-east and south were more prone for landslide events. The drainage map was also prepared from the DEM data. The first, second, third, fourth and fifth order drainageswere taken into consideration to prepare a drainage buffer map. For drainage buffer map preparation, 50m, 100m and more than 100m widths from drainage network were taken. The area whichwas found near the drainage network was more prone to landslide.

4.2 Landslide susceptibility analysis using statistical approach

Dictionary meaning of Susceptibility is the state of being susceptible from some external factors. In this study slope, aspect, elevation, drainage buffer, lithology, fault buffer and land use land cover wereconsidered as external factors for landslide events.30m resolution TM satellite data was used for mapping of landslide inventory. Likewise, the LULC map was generated from same data to avoid the error that comes due to resolution. The SRTM DEM data having resolution 1 arc second (30m) was used. The digitized maps such as lithology,drainage and thrust fault buffermaps were resampled to cell size 30mX30m.

The selection of methods for landslide susceptibility depends on the available datasets and their importance in the study area. In this study, theStatistical approach has been chosen to obtain information based on the relationship between the causative factors responsible for instability and landslide distribution. The statistical approach isgroupedinto two parts i.e. bivariate statistical analysis and multivariate statistical technique. The bivariate statistical analysis depends on each



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thematic layers in comparison with existing landslide layers. The calculation of weight value for each responsible factor depends on the landslide density. All the layers were overlaid on landslide inventory data layers and the landslide densities were calculated for each of the instability causing factors (Kanungo et al., 2009). There are various bivariate methods available for landslide susceptibility analysis. Among them, Information value model was found to be most suitable for the analysis and the study.

4.2.1 Information Value Model (IVM)

This method was developed by van Westen (1997) for landslide hazard zonation which determines the occurrence of landslides in a specific area. This method is known as the simplification of Yin and Yan (1988) method (Saha et al., 2002). Landslide potential values were defined using information value method by Jade and Sarkar (1993) (Lin et al., 2004). The information value model was found out to be very useful to determine the individual effect of responsible factors for landslide occurrence (Pardeshi et al., 2013). The information value*li* for each parameter can be calculated as:

$$Ii = \log \frac{Si/Ni}{S/N}$$
(2)

In which: N = total number of grid cell, S = number of grid cells with landslide, Si = number of grid cells with parameter i and containing landslide, Ni = number of grid cells with the parameter i.

The total information value in a grid cell j is:

$$Ij = \sum_{i=1}^{M} XjiIi \tag{3}$$

Here, X_{ji} is the value of parameter i; J = 1, 2, ..., N and i = 1, 2, ..., M; $X_{ji} = 1$, if parameter i exists in grid cell j; $X_{ji} = 0$, if parameter i does not exist in grid cell j; M =number of parameters considered.

By using above model, the information values for different categories of the responsible factors were calculated. After summation of all the information values of each cell of all the categories of each factors, the landslide susceptibility index was calculated. This indexgenerated the landslide susceptibility map. The landslide susceptibility index showed arange of numerical values. These values are directly proportional to the degree of landslide susceptibility. Lower the information value lower will be the susceptibility while higher the information value higher will be the susceptibility.

4.2.2 Landslide susceptibility analysis in GIS Environment

As mentioned above, nine thematic layerswere generated with a cell size of 30m X 30m. The total number of cells present in the study area is 808576. Out of these cells, 3170 cells belong to the landslide events. The cells containing landslides were extracted from each parameter of each factor. To carry out this process, each layer was joined with landslide inventory map to extract the landslide pixels of each corresponding parameters. Along with this, the total no. of cells for each class of each layerwas also calculated. The information value was calculated from equation 1 for each of the classes of each layer.

The information values of all the layers were listed in table no. 3 The information values mentioned in the table inferred that the lowest NDVI class had higher information value and vice versa. In most of the study, it was reported that the areas where less vegetation cover was more prone for landslide occurrence (Dai et al., 2001). The low NDVI areas were represented by snow, rocky or barren land which was more susceptible to landslides. Similarly, the forested or healthy vegetation area which falls under high NDVI category pertains to negative information value. The land use change plays a very important role for rainfall triggered landslides (Glade Thomas, 2003). The study done by Mehrotra et al. (1996) said that the landslide occurrences increased by 15% in those areas where the vegetation canopy has been removed or changed. The barren land and sparsely vegetated regions belong to more erosional activity and hence more instability in comparison to forested regions (Karsil et al., 2009). In this study, the barren land highest information values followed by built up and other LULC classes. In most of the studies, the slope angle was considered a very important factor for landslide studies because it is directly related to slope angle. The landslide occurrence varies from site to site and it occurs at certain critical slope angles. In many studies (Sarkar, 2008; Dhakal et al., 2000; Mondal et



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al., 2008; Saha et al., 2002), the steepest slope was found more responsible for landslide occurrence rather than a gentle slope.

The present study also showed the same result where the slope angle more than 54^{0} had highest information values and lower slope angles had lower information values which affects less on landslide occurrence. The direction of the slope i.e. aspect also influences the landslide susceptibility (Dai et al., 2001). In this study, the south and south-east direction had highest information values. It can be seen from the above table that the frequency of landslide was highest in south and southeast facing slopes. Various lithological units demonstrate thevarious active geomorphological processes. Therefore, the geology is a very important factor for landslide study. One important factor of geology is weathering degree of the units (Karsli et al., 2009). In this study, Greywacke rocks show high information value for landslide susceptibility. Greywacke comprises of deformed forms of sandstone that metamorphosed into greywacke semischist or schist (Allen at al., 2011). In the vicinity of the drainage channel, the possibility of landslide occurrence is very high in most parts of the study area. The present study also shows similar results where the 0-50m buffer has highest information values. It was found out that the areas which were nearest to the thrust had high information values. As the distance from the thrust increases, the possibility of occurrence of landslides also decreases.

Factors Categories		Information		
		value		
NDVI	Low NDVI	1.559574		
	Moderate NDVI	1.083745		
	High NDVI	-0.75763		
Road	0-50 m	-0.65099		
buffer	50-100 m	-0.39146		
	100-200 m	-0.23157		
	200-1000 m	-0.29734		
	>1000 m	0.130246		
Landuse/	Forest	-1.34243		
Landcover	Scurbland	-0.21602		
	Waterbodies	-2.62043		
	Agricultural land	-0.13028		
	Builtup area	1.025384		
	Glacier	0		
	Barren land	2.401798		
Slope	$0-14.41^{\circ}$	-0.86775		
	$14.41-24.03^{\circ}$	-0.50221		
	$24.03-32.27^{\circ}$	-0.05298		
	$32.27-41.54^{\circ}$	0.131826		
	$41.54-54.58^{\circ}$	0.557084		
	$54.58-87.20^{\circ}$	2.231789		
Aspect	North	-1.85178		
	North-East	-1.18915		
	East	0.283742		
	South-East	0.590651		
	South	0.659975		
	South-West	-0.0861		
	West	-0.69242		
	North-West	-1.86812		
Elevation	0-1023 m	0.201857		
	1023-1699 m	0.396072		

Table 3:Information value of all factors categories

Factors	Categories	Information
		value
	1699-2499 m	-0.02933
	2499-3552 m	-1.95018
	3552-5728 m	0
Geology	Phyllite	0
	Schist	0
	Dolostone	0
	Quartzite	0
	Shale	0
	Greywacke	1.338333
	Chlorite	0.299154
	Sandstone	-0.46658
	Gneiss	0
Drainage	0-50 m	0.560576
buffer	50-100 m	0.098605
	>100 m	-0.28146
Thrust fault	0-1 km	-0.6659
buffer	1-2 km	0.630145
	2-3 km	-0.00905
	3-4 km	-0.12228
	4-5 km	-0.75418
	>5 km	-0.02741



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There were nine major factors considered to categorize the landslide susceptible zones. Overall 52 various classes were extracted from these major categories. By information values, top ten important factors were identified and decreasing order of information values of these factors are; barren land, $54^0 - 87^0$ slope, low NDVI, Greywacke rocks, Moderate NDVI, Built up area, South aspect and 1-2 km thrust fault buffer. From this data, it was clear that the LULC, lithology, slope and NDVI were major contributing factors for landslide occurrence in the study area.

After getting the information values of each layer from equation 2, all these thematic layers were integrated into ArcGIS software. The raster calculator of spatial analyst tool was used to get the final landslide susceptibility map. After integration of all the raster layers, the landslide susceptibility index value of each cell was generated. It ranged from -7.69 to 9.06. On the basis of these values, the study area had been classified into five categories. These were very low, low, moderate, high and very high as shown in table no. 4 Area-wise, moderate landslide susceptible zones were dominant in the study area. The northern part of the study area is mostly covered with snow and glaciers lacking vegetation. Rest of the area comes under high to very high category due to the high slope, low vegetation and lithological factors.



Figure 5 Landslide susceptibility map

Fable 4 I	andslide	susceptibility	index of all	susceptible :	zones
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Landslide susceptibility class	Area (Km ²)	Area (%)	Landslide susceptibility index
Very low	107.33	15.93	-7.69 to -3.74
Low	189.08	28.06	-3.74 to -2.03
Moderate	203.34	30.17	-2.03 to -0.46
High	135.57	20.12	-0.46 to 1.96
Very High	38.58	5.72	1.96 to 9.06



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4.3 Landslide susceptibility map validation:

The landslideswere grouped under five classes i.e. high, very high, moderate, low and very low susceptible zones. These zones were superimposed on landslide inventory map and it is validating the area which was identified on inventory map. The mapwasalso validated by the existing landslide points available in the report. On the basis of these points, the accuracy assessment had been done. The Kappa analysis is a discrete multivariate technique used in accuracy assessment. The result of Kappa analysis is a KHAT statistic. The value of KHAT statistic ranges from +1 to -1 (Congalton and Green, 2008). The value of KHAT falls under three categories: values greater than 0.80 (>80%) shows strong agreement; between 0.40 and 0.80 (40-80%) for moderate agreement; and values below 0.40 (<40%) represent poor agreement(Landis and Koch, 1977).

The accuracy assessment was done using ERDAS Imagine 9.1 software. The overall classification accuracy for the landslide susceptibility map is 82.35% and the Kappa statistics was 0.73. This kappa value shows strong agreement validating that the landslide susceptibility map has been correctly classified.

V. CONCLUSION

The present study aims at determining the landslide susceptibility mapping using geospatial techniques. GIS played a significant role to analyze all the causative factors governing the slope failure in the study area. All the factors pertained a significant importance for slope failures therefore a significant value needs to be determined. A well-known technique had been used to calculate the importance of all the factors called as Information value model. It was a bivariate statistical technique which was supported by various researchers and scientists. It helped to find the weightage of each parameter and a susceptible map had prepared.

The susceptible map had been prepared on the basis of landslide inventory map. There were various points identified from the Government reports which was collected from official websites of South Sikkim. These points were overlaid on the landslide susceptibility map and verified by using accuracy assessment method in ERDAS Imagine software. A strong correlation was found in between the points and landslide susceptible zones which were shown by Kappa statistics. Most of the areas which lie near the vicinity of river, drainage and less vegetated areas such as barren land and scrubland were found to be in high susceptible zones.

The present study was an attempt to demarcate the whole study area into various landslide susceptible zones. However, more thorough analysis is required with more inputs of data such as earthquake and rainfall to give more accurate results. This type of analysis is very much useful to those people and stakeholders who are planning for any residential or developmental projects in the future.

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