Modeling Susceptibility to Landslides using Frequency Ratio and Weight of Evidence methods at Uttarakhand

Sonam Devi[1], Dr. R.K.Shukla[2], Mr. Vivek Saxena[3]

[1]Department of Hill Area Development Engineering, Madan Mohan Malaviya University of Technology Gorakhpur, U.P., India
[2]Associate Professor, Department of Civil Engineering, Madan Mohan Malaviya University of Technology Gorakhpur, U.P., India
[3]Scientist 'F', DTRL Lab, Defense Research and Development Organization, New Delhi, India

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Abstract - Landslide is a major cause to losses of human life and property. Landslide susceptibility mapping is useful for identification and planning disaster prone area. The main purpose of doing landslide susceptibility mapping is to reduce the loss of property and life. In this study compared the different methods such as Frequency Ratio (FR) and Weight of evidence method. The thematic layers casual factors such as litho logy, land cover, slope, aspect, plane curvature, profile curvature, topographic wetness index (TWI), stream power index (SPI), stream transport index (STI), buffer river, buffer road, buffer fault. Landslides observed in study area and the performance of different model evaluate. A number of qualitative and quantitative approaches can also be used to evaluate the landslide susceptibility maps. In this study a Bayes' theorem method-weight of evidence is occupied to analyze the data. Landslide Susceptibility Index maps were induces by subsidizing a correlation between landslides events and the casual factors of the map. Categorical color variations between boundaries of the lithology were viewable in the maps. The reason for this was the weighting process and reduces the frequency ratio because if higher the ratio was, the higher the landslide occurrence. The highest range of slope angle is from where the landslide scattering diffuse varied between study areas.

Key Words: **Landslides, GIS, Frequency Ratio, Weight of evidence, thematic layers.**

1. INTRODUCTION

Landslides occur due to a compound of casual appliances and susceptibility factors such as topographical factors, geological factors, environmental factors, anthropogenic factors and natural climatic conditions i.e. rainfall, earthquake and vegetation decadence (Gerrard and Gardner 2002, Wobus et al. 2003, Hasegawa et al. 2009). Landslide susceptibility varies from one region to another in Uttrakhand. The main origin of devoted water for humans living as well as for agriculture is considered rainfall in the Uttarakhand State. Landslides disturb people, groundwork and property regularly in Uttarakhand. Unfortunately, due to landslides the economic cost is affected badly and also loss of life and money is high (Petley et al. 2004). However several susceptible locations are not identified up to know. Therefore, for understanding about landslides susceptibility and their effects on affected area is an essential subject given the expenditure of landslides. Several researcher indicate that susceptibility maintain 'where' landslide will occur whereas danger stands for 'when' landslide will exist (Guzzetti et al. 1999; van Westen et al. 2006). In the perform study, we can define of landslide susceptibility followed to carry out the recognition of landslide prone region (Fell et al. 2008).

To determine landslide prone area a number of distinct methods are applicable. Several researchers experiment to grouping landslide risk vicinity technique (Guzzetti et al. 1999; Aleotti and Chowdhury 1999; Guzzetti et al.2005; Kanungo et al. 2009). In general, landslide susceptibility methods can be drawn through different methods: qualitative, semi quantitative and quantitative methods. Qualitative methods involve such as geologic mapping path, heuristic path and other individual judgment path (Zimmerman et al. 1986; Anbalagan 1992; Nagarajan et al. 1998; Gupta et al.1999; Saha et al. 2002). To study the Semi-quantitative methods are weighing and valuation depends on logical mechanism such as AHP, logistic regression, combined landslide frequency ratio and weighted of evidence (Ercanoglu and Gokceoglu 2004; Kanungo et al. 2006; Champatiray 2007; Yalcin 2008; Pradhan and Lee 2009; Mondal et al. 2012; Kayastha et al. 2013). Quantitative methods are probability based on assumption that the occurrence of landslide conditioning factors in any hazard zone and landslides are constantly divided in an area. Quantitative methods are classified with the help bivariate and multivariate classes. Bivariate landslide susceptibility method is based totally on hyperlink between ancient landslide information and landslide density in elements (Dai and Lee 2002; Lee and Pradhan 2007; Mathew et al. 2007; Dahal et al. 2008; Pradhan and Lee 2010; Ghosh et al. 2011; Kumar and Anbalagan, 2013). It considers landslide as dependent variable whereas factors as independent variables and are considered individually for susceptibility assessment. Multivariate techniques are also records driven however in this case, combined have an impact on of things on based variables are mathematically synthesized and have an impact on of character elements can also be obtained in numerical form (Lee 2005; Yesilnacar and Topal 2005; Lee and Pradhan 2007; Mathew et al. 2007; Pradhan and Lee 2010; Das et al. 2010; Das et al. 2012; Kundu et al. 2013). Quantitative method is also called deterministic method which is based on physical conservation laws. Deterministic method analysis is based on safety of slope, structural interruption, rainfall etc. This gives result in the form of competition of guarantee of especial slope (Sharma et al. 1995; Singh et al. 2008; Chakraborty and Anbalagan 2008).

1.1 Study Area

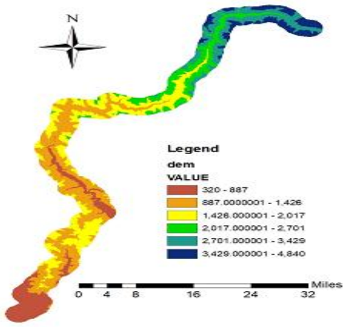
Rocks of the study area correlate to the following deposit-phyllite, sandstone with shale and sandstone, unconsolidated sediments/materials, Shale with limestone, Granites, Quartzite and Quartzite alternating with slates, Dolomite/marble, Limestone.
Rishikesh falls under longitude/latitude of 78.294754° E and 30.103368° N respectively. Gangotri falls under longitude/latitude of 78.93° E and 30.98° N respectively and covering a total area 109.85 km^2. The elevation of Gangotri is 3415m. Total 14 causative factors were chosen for the susceptibility analysis of the region. Acquisition of landslide causative factors was carried out using a variety of data sources. Table refers to various data used in the present study. The highest rainfall according to many researchers is counted 444mm and minimum rainfall is 10mm. In the study area the land use and land cover is consist of different factors such as high vegetation, low vegetation, moderate vegetation, barren land, settlement, water body and agriculture land. The annual rainfall of the Uttarakhand State is spatial and there is a wide variation in annual rainfall amount. Topography of the study area is showing steep slope $(0^\circ\ to\ 74^\circ)$. The aspect range vary in the study area is (-1 to 360 degree).

1.2 Data Prepation

Steep topography of the area, unfavourable lithology and structural discontinuities as well as nature of soil is the major reasons for the instability in the region. (Gupta and Anbalagan 1997:Kumar and Anbalagan 2013). These elements are called trigger mechanisms (for example rainfall, earthquake and seismic events) and susceptibility factors (such as steep slopes, rugged topography, sparse vegetation cover, fragile geological formations and structurally fragmented rock materials) (Wieczorek 1996). The main natural factors which are important for subjected to generate landslides such as geological factors, anthropogenic factors, topographical factors, environmental factors are comprised. These factors are described as follows:

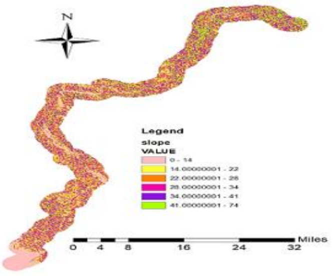
DEM

In this study we have used DEM of cell size 30*30 prepared using the Arc view 3D analyst and it is useful to derive elevation, slope, slope length, aspect, curvature etc. A viva (1992) specifies that these situations and terms are likely to disturb slope stability. Significance of elevation on landslide susceptibility is an object open to dispute, and this problem is still to be simplified by the analyzer. However, some analyzer appropriate the elevation data in the calculating of landslide susceptibility (e.g., Dai and Lee 2002; Gómez and Kavzoglu 2005). Whereas we can that an important factor in the study of earthquake induced landslides are digital elevation model (Kamp et al., 2008; Wang et al., 2015).



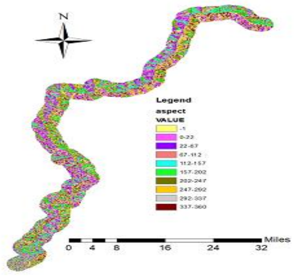
SLOPE

Slope angle is the most important parameter in the slope stability analysis (Lee and Min 2001). Because the landslides is the slope angle is directly linked to the slope angles and it is regularly used in adapting for landslide susceptibility maps (Clerici et al. 2002; Saha et al. 2005; Cevik and Topal 2003; Ercanoglu and Gokceoglu 2004; Lee et al. 2004a; Lee 2005; Yalcin 2005). With the help of Dem data slope map of the study area is prepared, and divided into six slope categories. In the map showing the range of slope minimum to maximum in the study area $(0^\circ\ to\ 74^\circ)$. The slope map of the study area are represented by quantile interval, and six subclasses (0-11, 11-22, 22-31, 31-39, 39-48, 48-74) were formed. For controlling the stability of slopes are the most important factor slope angles.

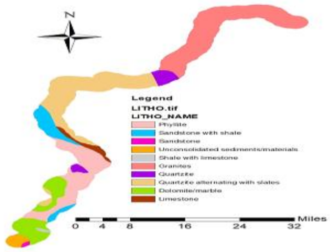


ASPECT

The aspect of the slope appears like the wetness detention and it's relation to elevation of bed linen of the mineral evolution which in turn affects the environmental factors of slope substantial and it's susceptibility to collapse (Dai et al., 2001). Aspect is too treated as a landslide modify factor, and this specification has been expressed in many other studies (Van Westen and Bonilla 1990; Gokceoglu and Aksoy 1996; Saha et al. 2005; Ercanoglu and Gokceoglu 2004; Lee et al. 2004a, b; Yalcin 2005). Slope stability is mainly affecting by some of the meteorological events such as the direction of the rainfall, amount of sunshine, the morphologic structure of the area (Mohammadi 2008).



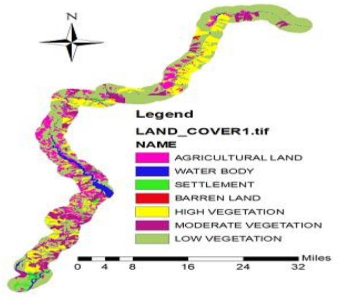
LITHOLOGY



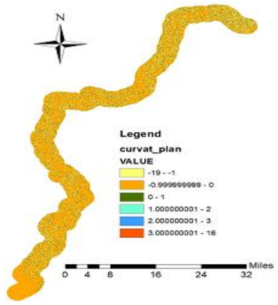
Significant conversions were integrated after field verification or digitizing in system to prepare the lithology map. There are ten rock types present in the area. These are phyllite, sandstone with shale, unconsolidated sediments/materials, and shale with limestone, granites, quartzite alternating with shale, dolomite/marble, and limestone. The lithology property of the land surface is used to control the landslides. Since various lithologic sections have various landslide susceptibility values, the data providing for susceptibility mapping lithology is very important. For this reason, it is important to category the lithologic premises perfectly (Carrara et al. 1991; Anbalagan 1992; Mejia-Navarro and Wohl 1994; Mejia-Navarro and Garcia 1996; Pachauri et al. 1998; Luzi and Pergalani 1999; Dai et al. 2001; Yalcin 2005; Duman et al. 2006).

LAND USE AND LAND COVER (LULC)

In this study, a land use map was prepared from the Google image by applying a supervised classification scheme and digitize by defining polygon. There are seven types of LULC are identified in the study area: low vegetation, high vegetation, moderate vegetation, agriculture land, river, settlement and barren land. The study area is categorized in several classes according to the ground truth and digitizes 0.5m*0.5m resolution. In the study area, the dimensional relationship between LULC factor and landslide occurrence are describe.

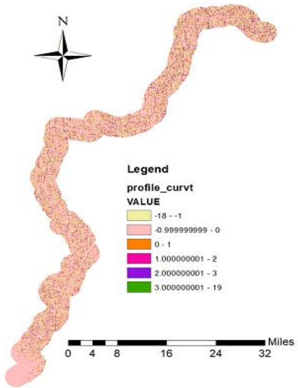


PLAN CURVATURE



The term curvature is apparently defined as the percentage of difference of slope gradient or aspect, mainly in a distinct direction (Wilson and Gallant 2000). In this method the curvature value of our study area can be calculated by calculating the corresponding value of the radius of curvature of that distinct guidance. Hence, while the curvature value positive indicates the surface plane is showing as sideward convex whereas negative value indicates the surface plan is sideward concave. But when the curvature value zero then it indicates that the surface plan is linear (flat).

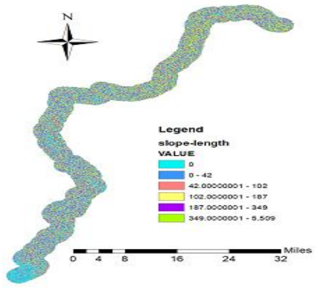
PROFILE CURVATURE



Profile curvature is equidistant to the direction of the greatest slope. A negative value illustrate that the surface is ascending convex at that unit. A positive figure illustrate that the surface is ascending concave at that unit. A value of zero illustrate that the surface is strait. Profile curvature disturbs the dispatch or deceleration of outflow transversely of the surface. Mark that this is the similar as the strait, convex, and concave slopes presenting with the help of arcgis software.

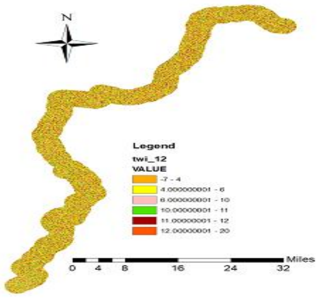
SLOPE LENGTH

In many GIS based applications including landslides and soil erosions a parameter is also considering such as slope length (Hickey 2000; Gómez and Kavzoglu 2005). Slope length can be defined as the distance along a slope subject to uninterrupted overland flow. It is a relevant component in landslide movement as high slope lengths increment the capability of eroding agents to transit component downfall (Gómez and Kavzoglu 2005). Brief slope lengths guidance to confined discharge velocity; therefore, soil multitude cannot obtain sufficient discharge energy to segregate and transit materials over downfall (Chaplot and Le Bissonnais 2000). Slope lengths are figure out on the uniform and natural to the lineaments on the plane of the slope. The slope map of the study area is calculated by DEM data with the help of Arcgis software and it is divided into six subclasses at quantile intervals.



TOPOGRAPHIC WETNESS INDEX

According to many research paper and different researcher topographic wetness index (TWI) can be defined as broadly the effect of topography of the study area and slope. Moore et al. (1991) proposed Equation below TWI can be calculated according the assumption of the behaviour of system or process is unchanging in time and uniform soil properties.



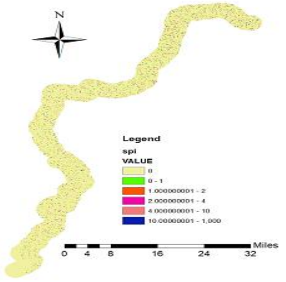
$$TWI = \ln(As/\tan\beta)$$

Where As is the flow accumulation (m^2), and β is slope gradient (in radian).

According to Wood et al. (1990), the variation in the topographical components is often far greater than the local variability in soil transmisivity, and above given equation can be used to calculate TWI. The TWI map was formed using the characters written by Hengl et al. (2003) and run in arcgis 10.3 software.

STREAM POWER INDEX (SPI)

The stream power index (SPI) is determine of the dissolvent capability of water flow established on the presumption that discharge (q) is corresponding to flow accumulation (catchment area As) (Moore et al. 1991). SPI calculated with the help of given equation below,



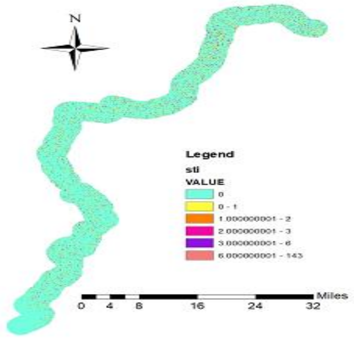
$$SPI = A_s \times tan\beta$$

Where A is the flow accumulation and catchment area (m^2) and β is the slope gradient in radian. As the flow accumulation and angle increase, the volume of water subsidize by upslope areas and the rate of water flow raise; thus, the SPI and slope-abrasion hazard raise (Moore et al. 1991). Moore et al. (1993) explain that the SPI regulate the inherent abrasion capacity of overland discharge. Thus, these mechanism can be examined as particular of the segment of landslide existence (Lee and Min 2001; Gokceoglu et al. 2005; Nefeslioglu et al. 2008; Yilmaz 2009; Akgun and Turk 2010).

STREAM TRANSPORT INDEX (STI)

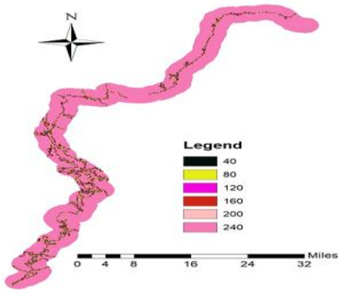
One more formula often used to follow the dissolvent power of the overland discharge is the sediment transport index (Moore et al. 1993). We can used to calculate the STI this formula given as below:

$$STI = \left(\frac{A_s}{22.13}\right)^{0.6} \left(\frac{sin\beta}{0.0896}\right)^{1.3}$$



Where As is the flow accumulation and catchment area (m^2) and β is the slope gradient in radian. The Universal Soil Loss Equation resembles to this empirical formula and can thus be detect to illustrate locations of inherent abrasion risk (Moore and Burch 1986). If a close research on Eq. is maintain, it is explain that the environmental meaning of this ingredient is the capacity of sediment transportation restrained a flow accumulation and slope gradient. For that reason, the main purpose for these circumstances perhaps the disrupted drainage system and the small slope gradient direction on landslide shapes. Therefore, this prescribed deviation can be express as a good symbol of landslide appearance (Nefeslioglu et al. 2008). The STI map was originated using the characters written by Hengl et al. (2003) and run in ArcGis 10.3 software and the dimensional interrelation between TWI, SPI, STI, and landslide appearance are originated.

BUFFER ROAD

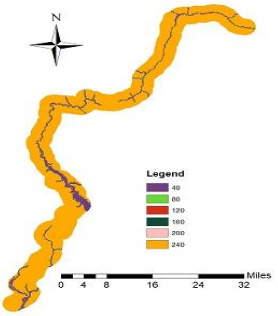


Similar to the impact of the distance to streams, landslides may also arise on the street and on the side of the slopes laid low with roads (Pachauri and Pant 1992; Pachauri et al. 1998; Ayalew and Yamagishi 2005; Yalcin 2005). A Street design beside slopes causes a decrease within the load on both the topography and on the toe of slope.

Although a slope is evened before the street construction, little instability can be observed because of negative effects of excavation. In fact, at some stage in the field works, a few landslides have been recorded whose origin may be attributed to road construction. For this reason, six unique buffer regions are created (0-40, 40-80, 80-120, 120-160, 160-200, 200-240) on the route of the road on the stability of slope. The landslide percentage distribution and its frequency ratio are determined thinking about the gap training to the street completed with the aid of comparing the map of the distance to the road and the landslide inventory.

BUFFER RIVER

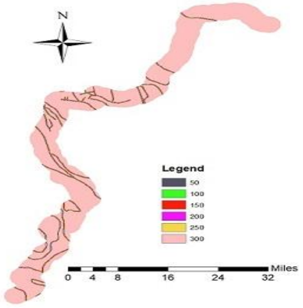
An essential parameter that controls the stability of a slope is the saturation degree of the fabric at the slope. The closeness of the slope to drainage system is another essential factor in terms of balance.



Streams might also adversely affect stability with the aid of eroding the slopes or by using saturating the lower a part of cloth until resulting in water level increases (Gokceoglu and Aksoy 1996). Six one of a kind buffer zones are created (0-40, 40-80, 80-120, 120-160, 160-200, 200-240) inside the observe area to determine the degree to which the streams affected the slopes.

BUFFER FAULT

The distance from fault is calculated at 50 m intervals using the lithology map. Faults form a line or sector of weak point characterized by way of closely fractured rocks. Selective



erosion and motion of water along fault planes sell such phenomena. Besides the principal thrusts and faults at the geological maps complementary facts concerning feasible faults and structural dislocations have been identified as lineaments via method of image improvement (filtering) of satellite imagery. The reputation of lineaments as viable faults is achieved step-with the aid of-step shape big to smaller order lineaments taking into consideration the spatial scale of the study.

2. METHODOLOGY

LANDSLIDE SUSCEPTIBILITY ANALYSIS METHODS

Landslide inventory is a spatial or temporal data type it is also called frequency method and this method is the simplest form of landslide mapping. The susceptibility estimation is based on the number of landslide occurrence (Wright et al. 1974). Landslide inventory maps produce a reliable and qualitative output on landslide rationing. They provide comparison between the landslide distribution and the casual factors of different regions. Landslide inventory can be analyzed by different variety of techniques. Similarly weight of evidence method is also used to prepare landslide susceptibility map with the help of weight of contrast value. In this study, Weight of evidence and frequency ratio methods are applied to landslide susceptibility assessment using 14 factors defining below:

Frequency Ratio

In probability models for the prediction of landslide hazard, the hazard at each point or pixel is considered to be the joint conditional probability that the pixel will be suffering from a destiny landslide given (conditional to) facts from the spatial enter information at the pixel (Chung and Fabbri 1999). To construct a probability model for landslide susceptibility mapping, it is important to assume that landslide existence is decided by landslide-interconnected factors, and that forthcoming landslides will occur under the same situation as old day's landslides. The FR model is commonly used for landslide hazard analysis (Lee and Dan 2005; Lee and Sambath 2006; Lee and Pradhan 2007; Akgun et al. 2008; Yilmaz 2009; Jadda et al. 2009; Erener and Du¨zgu¨n 2010; Akgun 2012).

The frequency ratio is the ratio of the place where landslide occurred within the general observes area, and also is the ratio of the chances of landslide prevalence to a non-occurrence for a given attribute (Bonham-Carter, 1994; Lee and Talib, 2005). The 14 factors were transformed to a pixel format to calculate the landslide susceptibility index. Using Arcgis 10.3 software, the pixels were superimposed with the topographical coverage of the study area. For superimposed process, the summation of each factor ratio equal to landslide susceptibility index (LSI). The larger the value is, the higher is the risk of landslide occurrence (Lee and Pradhan 2007; Lee and Dan 2005). It is defined as

$LSI = \Sigma\ Fr$

Where, FR is a ratio of percentage of landslide to percentage of class.

WEIGHT OF EVIDENCE

WOE is a data-driven method (Bonham-Carter, 1994), which is basically the Bayesian approach in a log-linear form (Spiegelhalter, 1986) and uses prior (unconditional) probability and posterior (conditional) probability. The method is applicable when sufficient data are available to estimate the relative importance of evidential themes via statistical means (Bonham-Carter, 1994). The prior probability is the probability of an action, determined by the ratio of total no of landslides in study area divided by total study area. If a landslide causing factor "F" exists, the probability of occurrence of landslides based on this factor might change. Then, the favorability for predicting the landslides, given the presence of the evidence factor, can be expressed by the conditional probability (P{L|F}) (Bonham-Carter, 2002):

$$P\{L\backslash F\} = \left(\frac{P\{L\cap F\}}{P\{F\}}\right)$$

(1)

In terms of the number (N) of the cells occupied by L and F, the equation can be rewritten as:

$$P\{L\backslash F\} = \left(\frac{N\{L\cap F\}}{N\{F\}}\right)$$

(2)

Similarly, the conditional probability of landslides based on factor F is:

$$P\{F\backslash L\} = \left(\frac{P\{L\cap F\}}{P\{L\}}\right)$$

(3)

P{F∩L} and P{L∩F} are the same, so from Eqs. (1) and (3)

$$P\{L\backslash F\} = P\{L\}\left(\frac{P\{F\backslash L\}}{P\{F\}}\right)$$

(4)

This states that the conditional (posterior) probability of a landslide, given the presence of the factor F, equals the prior probability of the landslide P{L} multiplied by the factor P{F|L}/P{F}. Similarly, the posterior probability of a landslide, given the absence of the factor, can be determined as:

$$P\{L\backslash \bar{F}\} = P\{F\}\left(\frac{P\{\bar{F}\backslash L\}}{P\{F\}}\right)$$

A similar model can be expressed in an odds form, the ratio of P/ (1– P). The odds of a landslide are expressed as:

$$O\{L\} = \frac{Probability\ that\ an\ event\ will\ occur}{Probability\ that\ an\ event\ will\ not\ occur} = \frac{P\{L\}}{1-P\{L\}} = \frac{P\{L\}}{P\{\bar{L}\}} \quad (6)$$

Likewise,

$$O\{L\backslash F\} = \frac{P\{L\backslash F\}}{1-P\{L\backslash F\}} = \frac{P\{L\backslash F\}}{P\{\bar{L}\backslash F\}} \quad (7)$$

Dividing both sides of the Eq. (4) by $P\{\bar{L}/F\}$

$$\frac{P\{L\backslash F\}}{P\{\bar{L}\backslash F\}} = \frac{P\{L\}P\{F\backslash L\}}{P\{\bar{L}\backslash F\}P\{F\}} \quad (8)$$

Similar to Eqs. (1) and (4), from the definition of the conditional probability is:

$$P\{\{\bar{L}\backslash F\} = \frac{P\{\bar{L}\cap F\}}{P\{F\}} = \frac{P\{F\backslash \bar{L}\}P\{\bar{L}\}}{P\{F\}} \quad (9)$$

Substituting the value of P{L ⌈F} in the right side of Eq. (8), produces:

$$\frac{P\{L\backslash F\}}{P\{\bar{L}\backslash F\}} = \frac{P\{L\}P\{F\backslash L\}}{P\{\bar{L}\}P\{F\backslash \bar{L}\}} \quad (10)$$

From Eqs. (6), (7), and (10), it can be rewritten as:

$$O\{L\backslash F\} = O\{L\}\frac{P\{F\backslash L\}}{P\{F\backslash \bar{L}\}} \quad (11)$$

Where O{L|F} is the conditional (posterior) odds of L given F, and O{L} is the prior odds of F. P{F\L}|P{F\L̄} is known as the sufficiency ratio LS (Bonham-Carter, 2002). In WOE, the logical arithmetical of the sufficiency ratio is W+.

Thus,

$$W^{+} = \log_e\left(\frac{P\{F\backslash L\}}{P\{F\backslash \bar{L}\}}\right) \quad (12)$$

Similarly, taking the natural log of Eq. (11) on both sides produces:

$$W^{+} = \log_e\left(\frac{O\{L\backslash F\}}{O\{L\}}\right) \quad (13)$$

Similar algebraic manipulation leads to the derivation of an odds expression for the conditional probability of L given the absence of the factor. Thus,

$$O\{L\backslash \bar{F}\} = O\{L\}\frac{P\{\bar{F}\backslash L\}}{P\{\bar{F}\backslash \bar{L}\}} \quad (14)$$

The term P{ F⌉L}|P{ F⌉ L⌉} is known as the necessity ratio, LN (Bonham-Carter, 2002). W^{-} Is the logical arithmetical of LN. Thus,

$$W^{-} = \log_e\frac{P\{\bar{F}\backslash L\}}{P\{\bar{F}\backslash \bar{L}\}} \quad (15)$$

Similarly, taking the natural log of Eq. (11) on both sides gives:

$$W^{-} = \log_e\frac{O\{L\backslash \bar{F}\}}{O\{L\}} \quad (16)$$

LN and LS are also referred to as likelihood ratios. If the pattern is positively correlated, LS is greater than 1 ($W^{+} = positive$) and LN ranges from 0 to 1 ($W^{-} = negative$). If the pattern is negatively correlated, LN would be greater than 1 ($W^{-} = positive$) and LS ranges from 0 to 1 ($W^{+} = negative$). If the pattern is uncorrelated with a landslide, then LS=LN=1 ($W^{+} = W^{-} = 0$) and the posterior probability would equal the prior probability, and the probability of a landslide would be unaffected by the presence or absence of the factor. We used Eqs. (13) and (15) to calculate weights of the factors. When more than one factor occurs, it is necessary to combine weights of all the factors.

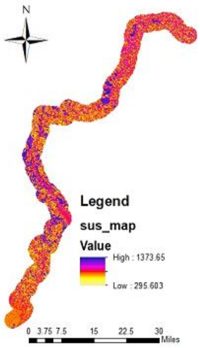
The final weight value are used to derive the contrast value (c) given by:

$$C = W^{+} - W\text{-}$$

3. RESULTS

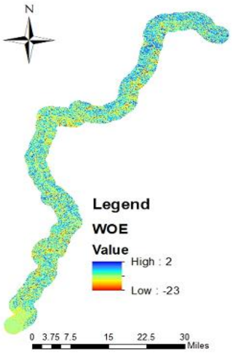
FREQUENCY RATIO

Using the probability model, Frequency ratios were calculated for 14 factors. The Frequency ratios for each factor type or range were calculated from their relationship to landslide events. In the case of the relationship between landslide occurrence and elevation, ratios greater than 1 were distributed at topographic elevations between 320 and 1263 m. We can say that if a slope angle above 22, the ratio was greater than 1, indicating a high probability of landslide occurrence. In the case of the relationship between landslide occurrence and Buffer River, the ratio was greater than 1 in both the area with the distance to river 40 m or below and 240 m or above. The ratio was highest (1.29) when TWI was 12–20, and was still high (greater then 1) even when TWI was in the range 11-12 and >4. The ratio was <1 except when SPI was in the range 0, and 1-2, and was highest when SPI was in the range 1-2. In the case of the relationship between landslide occurrence and lithology factor, the ratio was greater then1 for sandstone with shale, shale with limestone, granites, quartzite, dolomite/ marble and limestone. The ratio was high in plan curvature for flat surface. Regarding the profile curvature, the ratio was high for flat and convex surface. Whereas the ratio are greater than 1 for buffer fault and buffer road lies the range of 0-120 and >300.



WEIGHT OF EVIDENCE

The predictive capability of WOE for known and unknown landslides suggests that slope, aspect, curvature (plan and profile), soil plasticity index, flow accumulation, Buffer River, and buffer roads are sufficient to create an optimum and valid map of susceptibility to landslides of the study area. The high susceptibility zone has an amount of weight ranging from 3 to 0, the medium susceptibility has a rate of weight ranging from 0 to −2.5 and the low susceptibility has an amount of weight ranging from −2.5 to −5.16. On the susceptibility map, 30% of the region is shown as high susceptibility, 45% is shown as medium susceptibility and 25% is shown as low susceptibility. Showing the Susceptibility to landslides based on method factors and 155 landslides. This model has the highest fee of prediction. The high susceptibility (HS) area consists of 30% of the study area; it includes 50% of the total area of landslides. The medium susceptibility (MS) area consists of 55% of the study area and comprises 25% of the total area of landslides. The low susceptibility (LS) area consists of 25% of the study area and contains 45% of the total area of landslides. Quantile break of the curve were used to classify the total weight map into a map of susceptibility. The high susceptibility zone has a value of weight ranging from 3 to 0, the medium susceptibility has a value of weight ranging from 0 to −2.5 and the low susceptibility has a value of weight ranging from −2.5 to −5.16.



4. CONCLUSIONS

The introduce work is an efforts towards application of GIS for landslide hazard analysis based on statistical approach. 14 factors were selected and classified into various categories in the present study. GIS different type of application involved generation of thematic data layers extraction and their spatial analysis to detect the numerical weights of the subclasses of the factors in order of their influence for landslide reoccurrence. For determination of weights of the factor categories information model were used and it's found to be a useful method for landslide susceptibility mapping. All type of data analysis was taken out in GIS which is a best tool for data savage and retrieval, map preparation and performing complicated operations of voluminous data. Before implementation of any hill developmental project need to be investigate very high and high susceptible zones in detail. These types of landslide susceptibility maps are very helpful for planners for choosing suitable locations for developmental activities in hilly areas.

REFERENCES

[1] Sarkar, S., Kanungo, D. P., Patra, A. K., & Kumar, P. (2008). GIS based spatial data analysis for landslide susceptibility mapping. Journal of Mountain Science, 5(1), 52–62.

[2] Kumar, R., & Anbalagan, R. (2016). Landslide susceptibility mapping using analytical hierarchy process (AHP) in Tehri reservoir rim region, Uttarakhand. Journal of the Geological Society of India, 87(3), 271–286.

[3] Chen, W., Sun, Z., & Han, J. (2019). Landslide Susceptibility Modeling Using Integrated Ensemble Weights of Evidence with Logistic Regression and Random Forest Models. Applied Sciences, 9(1), 171.

[4] Varnes, D.J., 1978. Slope movements: types and processes. In: Schuster, R.L., Krizek, R.J. (Eds.), Landslide Analysis and Control. Transportation Research Board, Special Report No. 176. Washington, DC, pp. 11–33.

[5] Yilmaz C, Topal T, Suzen ML (2012) GIS-based landslide susceptibility mapping using bivariate statistical analysis in Devrek (Zonguldak Turkey). Environ Earth Sci 65(7):2161–2178

[6] Varnes DJ (1984) Landslide hazard zonation: a review of principles and practice. UNESCO, Paris, p 63 Wan S (2009)

[7] A spatial decision support system for extracting the core factors and thresholds for landslide susceptibility map. Eng Geol 108(3–4):237–251

[8] Van Westen CJ, Rengers N, Terlien M (1997) Prediction of the occurrence of slope instability phenomena through GIS-based hazard zonation. Geol Rundsch 86:4004– 4414

[9] Pachauri AK, Pant M (1992) Landslide hazard mapping based on geological attributes. Eng Geol 32:81–100

[10] Park NW (2010) Application of Dempster–Shafer theory of evidence to GIS-based landslide susceptibility analysis. Environ Earth Sci 62(2):367–376

[11] Sabatakakis N, Koukis G, Vassiliades E, Lainas S (2013) Landslide susceptibility zonation in Greece. Nat Hazards 65(1):523–543

[12] Chauhan S, Sharma M, Arora MK (2010) Landslide susceptibility zonation of the Chamoli region, Garhwal Himalayas, using logistic regression model. Landslides 7(4):411–423