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Research Article

LANDSLIDE SUSCEPTIBILITY MAPPING IN A PART OF UTTARKASHI DISTRICT (INDIA) BY MULTIPLE LINEAR REGRESSION METHOD

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ABSTRACT
The term “landslide” basically means a slow to rapid downward movement of instable rock and debris masses under the action of gravity. Landslides are one of the major natural hazards that account for hundreds of lives besides enormous damage to properties and blocking the communication links every year. The area chosen for the study is along tow side of the Bhagirathi river valley in Uttarkashi district of Uttarakhand, suffering from frequent landslides every year.
One of the enormous occurrences landslide in the study area is Varnavat pravat landslide in uttarkashis city and also and the most affected villages by landslide are *Maneri, Mala* and *Bhatwari*. The populations living in these townships and villages suffer badly from the onslaught of landslide. Therefore, landslide susceptibility mapping is one of the important issues for urban and rural planning in India.
In this study, layers are evaluated with the help of stability studies used to produce landslide susceptibility map by Multiple Linear Regression method. The parameters of slope, aspect, lithology, land cover, rainfall, distance from fault, distance from river, and distance from road were used as variables in the Multiple Linear Regression analysis. ILWIS 3.31 Academic, Arc GIS 9.3, Global Mapper 13.0 and Excel softwares have been used for zonation, and statistical analyses respectively. Finally, an overlay analysis was carried out by evaluating the layers obtained according to their accepted coefficient in final model. The result was validated using the Area Under Curve (AUC) method and temporal data of landslide occurrences. The validation results showed satisfactory agreement between the susceptibility map and the existing data on landslide locations. As a result, the success rate of the model (76.2 %) shows high prediction accuracy. The study area has been classified into five classes of relative landslide susceptibility, namely, Low, Moderate, High, and Very High.

Key Words: *India, Uttarkashi, Landslide Susceptibility Zonation, Multiple Linear Regression method, AUC*

INTRODUCTION
Landslides are one of the most frequently occurring disasters affecting human life and property in Himalaya. The term “landslide” basically means a slow to rapid downward movement of instable rock and debris masses under the action of gravity which can be categorized into various types on the basis of failure characteristics (Cruden, 1991). Vast expanse of areas in the country, particularly in the Himalaya and other hilly terrain, being highly fragile, is perennially under repeated threats of landslides and mass movements. Increase in population and rapid urbanization has led to expansion of construction activities in hilly terrain and has catapulted frequency of landslides to dramatic proportions in recent decades. Landslides are one of the major natural hazards that account for hundreds of lives besides enormous damage to properties and blocking the communication links every year. According to Geological Survey of India (GSI, 2009) 0.49 million km2 or 15% of land area of the country is vulnerable to landslide hazard. Out of these 0.098 million km2 is located in North-eastern Region and rest 80% is spread over Himalayas, Nilgiris, Ranchi Plateau and Eastern and Western Ghats. Especially in mountainous terrain the rain saturated steeper slopes are very much susceptible to landslides possessing direct risk to the properties, vehicles, and commuters. Other than direct risk these events possess indirect risk to the economic conditions of the society associated with these areas (Remondo, 2008). The study of landslides has drawn worldwide attention mainly due to increasing awareness of the socio-economic impacts of landslides (Aleotti and Chowdhury, 1999).
Every year during monsoon numerous landslides occur in the mountainous region of India. Landslides are one of the natural disasters which account for huge damage of properties in terms of direct and indirect risk (Dai *et al.* 2002). For many natural and anthropogenic reasons, western Himalaya Mountain in India is at the risk of a number of small and large-scale landslides which take their heavy tolls in this area. For instance the Alaknanda Tragedy of

July 1970, the Okhimath landslide of 1979, the Uttarkashi-Kedarghati landslide of 1981, the Gopeshwar Landslide in 1991, the Bhimtala landslide in 1996, the Great Malpa landslide of 1998 (Rautela and Pande, 2005), the second Alaknanda landslide of 1999 (Saha *et al.*, 2005), the Phata and Byung Gad landslides in 2001, the Landslides at Budhakeda in 2002(Rautela and Pande, 2005), the Varunavat Parvat landslide of 2003 (Gupta and Bist, 2004), the Sundardhunga Landslide of 2004, the Ramolsari landslide, the Govindghat landslide in Chamoli, and the Agastyamuni landslide in Rudraprayag 2005 (Rautela and Pande, 2005) are examples of severe landslides in Himalaya and India. One of the enormous occurrences landslide in the study area is Varnavat pravat landslide in uttarkashis city and also and the most affected villages by landslide are *Maneri*, *Mala* and *Bhatwari*. The populations living in these townships and villages suffer badly from the onslaught of landslide. All the landslides caused considerable damage to human life and property. Therefore, taking into account occurrence of landslides, and in order to mitigate the ensuing losses and consequences, landslide susceptibility is duly warranted; also landslide susceptibility mapping is one of the important issues for urban and rural planning in India.

Landslide susceptibility Zonation (LSZ) relies on a rather complex knowledge of slope movements and their controlling parameters. The reliability of landslide susceptibility maps depends mostly on the amount and quality of available data, the working scale and the selection of the appropriate methodology of analysis and modelling. The process of creating these maps involves several qualitative or quantitative approaches (Soeters and van Westen, 1996; Aleotti and Chowdhury, 1999; Guzzetti *et al*., 1999).

Qualitative methods depend on expert opinions. The most common types of qualitative method simply use landslide inventories to identify sites of similar geological and geomorphologic properties that are susceptible to failure. Some qualitative approaches, however, incorporate the idea of ranking and weighting, and may evolve to be semi-quantitative in nature. Examples are the use of the Analytic Hierarchy Process (AHP) of Saaty (1980) by Barredol *et al*., (2000) and Weighted Linear Combination (WLC) by Ayalew *et al*. (2004). AHP involves building a hierarchy of decision elements and then making comparisons between possible pairs in a matrix to give a weight for each element and also a consistency ratio. It is based on three principles: decomposition, comparative judgment and synthesis of priorities (Malczewski, 1999). WLC is a concept to combine maps of landslide-controlling parameters by applying a standardized score (primary-level weight) to each class of a certain parameter and a parameter weight (secondary-level weight) to the parameters themselves. Being partly subjective, results of these approaches vary depending upon the knowledge of experts. Hence, qualitative or semi-quantitative methods are often useful for regional studies (Soeters and van Westen, 1996; Guzzetti *et al*., 1999). Quantitative methods are particularly based on numerical expressions of the relationship between controlling parameters and landslides. There are two types of quantitative methods: deterministic and statistical (Aleotti and Chowdhury, 1999). Deterministic quantitative method depends on engineering principles of slope instability expressed in terms of parameter of safety. On account of the need for exhaustive data from individual slopes, these methods are often effective for mapping only smaller areas. Landslide susceptibility mapping using either multivariate or bivariate statistical approaches analyses the historical link between landslide-controlling parameters and the distribution of landslides sites (Guzzetti *et al*., 1999). Bivariate statistical analyses (BSA) involves compared of a landslide inventory map with maps of landslide influencing parameters in order to rank the corresponding classes according to their role in landslide formation. Ranking is normally carried out using landslide densities. A variety of multivariate statistical approaches (MSA) exist, but those commonly used to map landslide susceptibility include discriminant analyses and logistic regression. Stepwise discriminant analysis has been used by Carrara *et al*. (1991 and 2003) to classify stable and unstable slope-units in Italy. The method was also reported to be significant to define landslide susceptibility classes in the Spanish Eastern Pyrenees (Baeza and Corominas, 2001). Logistic regression has been applied for susceptibility mapping by a number of researchers including: (Guzzetti *et al.*, 1999); Die and Lee (2002); Ayalew and Yamagishi (2005); Chen and Wang (2007) and Pradhan and Lee (2010)).

Various methods have been introduced to LSZ, each of which has considered a number of factors. For instance, Pachauri *et al.,* (1998) used geotechnical parameters, distance from the nearest major lineament, slope gradient, relative relief, lithology, vegetation, road density, and distance from the nearest ridge top and relative altitude for zonation of landslide. Later Lee (2001) considered factors like slope gradient, slope aspect, soil thickness, proximity to flood-way, land use, and vegetation cover for delineating landslide susceptibility zonation. In a very interesting study Ayalew *et al.,* (2005) used factors like lithology, bed rock-slope relationship, lineaments, slope

gradient, aspect, elevation and road network for landslide zonation. In a similar exercise Saha *et al*., (2005) applied factors like slope, aspect, relative relief, lithology, buffer zones along thrusts, faults and lineaments, the drainage density and land cover. In this study, factors such as slope, aspect, lithology, land cover, rainfall, distance from fault, distance from river and distance from road have been used for modelling and zonation.
The scope of the study is to examine the long-term parameters and to define their relations to landslide occurrence in the studied area. The main goal of this study is assessment and appraisal of the Multiple Linear Regression modelling method in landslide susceptibility zonation and validation of landslide susceptibility map with inventory map of study area.

MATERIALS AND METHODS

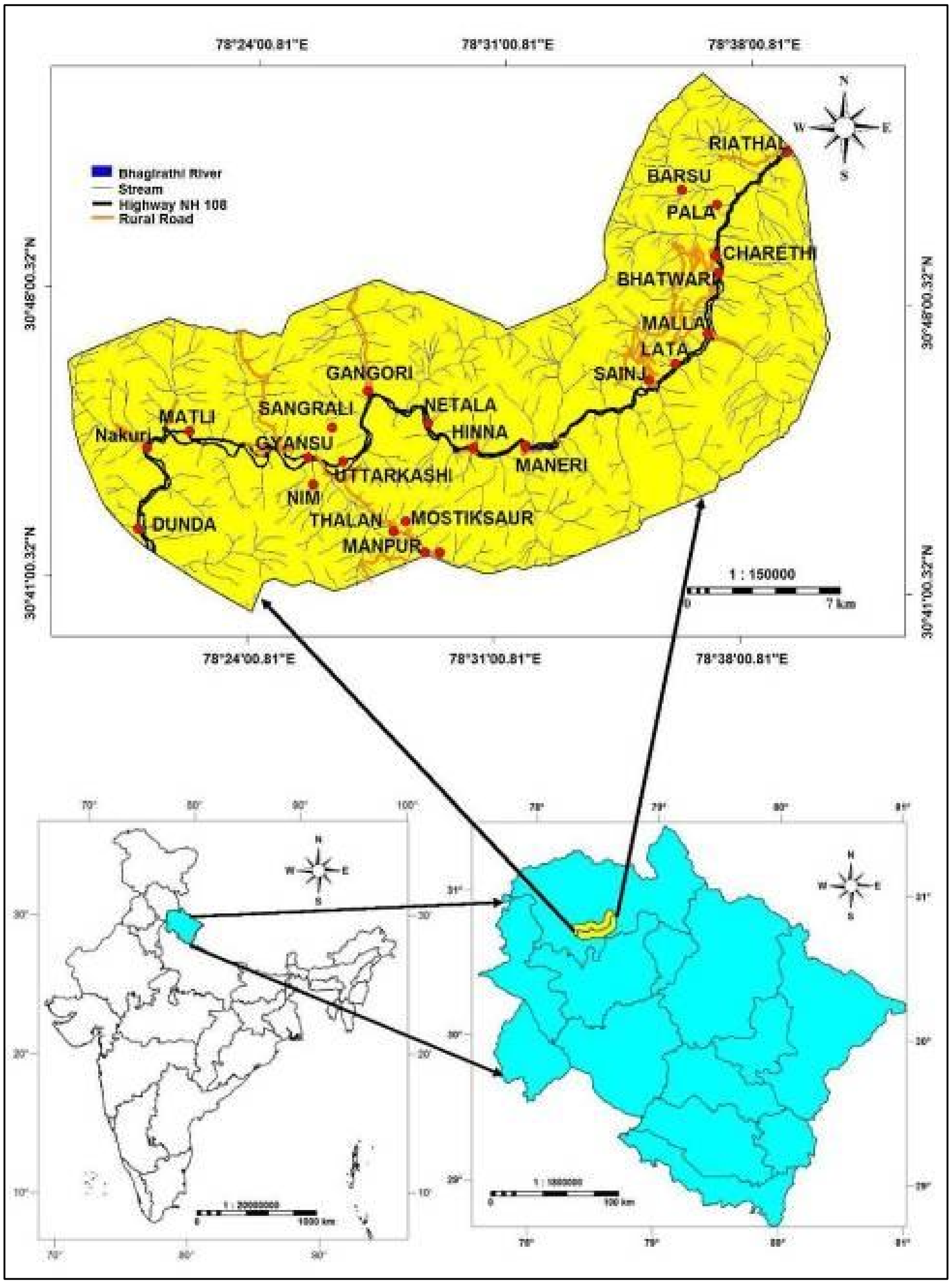
Study area

The area chosen for the study is along tow side of the Bhagirathi river valley in Uttarkashi district of Uttarakhand, suffering from frequent landslides every year. The state of Uttarakhand is presently made of 13 districts and divided into two major divisions namely Garhwal division and Kumaon division. Garhwal Himalaya in Uttarakhand state is well known for its fragile landscape and frequent geological hazards, among which landslides are the regular threats over this region.
Uttarkashi, an ancient religious town situated in the North Western part of Uttarakhand state. The selected study area is situated in southern part of Uttarkashi district and bounded by North Latitude 30° 34′ 55″ and 30° 56′ 33″ and East Longitude 78° 17′ 11″ and 78° 43′ 28″, and inside 5 Km distance buffer zone from the Bhagirathi River, it covers about 419.3 Km^2 of Uttarkashi district (*Fig. 1*).
The area receives heavy precipitation during the summer months between July and September and moderate rainfall during the winter months between Januarys to March. Elevation in the area ranges between 920 and 3830 m with respect to mean sea level and annual rainfall is approx. 1009.83 (mm).
The area is transacted by a major National Highway connecting Uttarkashi and Gangotri, in Uttarakhand state, India. A 53 kilometer road stretch between Dunda to Riathal on National highway 108 is selected for the research as the landslides susceptibility modelling. Slope failures are observed frequently during rainstorm and very often with disastrous condition. Landslides here are the outcome of complex tectonic and neo tectonic settings, unique geomorphic expressions with steep slopes, highly dissected hills, deep carved valleys accompanied by high pace of land degradation in association of climatic and other geo-environmental agents and human activities along the hill slopes. Slope failures are observed frequently during heavy shower and very often with catastrophic consequences.

Data and material used

Successful prediction of landslide occurrences and the preparation of a map showing landslide-prone areas call for collection of the relevant spatial data (Saha et al. 2005). The reliability and accuracy of the collected data affect the success of the applied method. Therefore, the relation between landslide occurrence and the conditioning parameters used is crucially important for the landslide susceptibility mapping. For landslide susceptibility assessment, several spatial data controlling landslide occurrence are necessary, together with landslide inventory data. When applying a method to landslide susceptibility assessment, defining the criteria controlling the degrees of susceptibility is very important (Kıncal et al. 2009).
Although any parameter may be important with respect to landslide occurrence for a given area, the same parameter may not be important for another area (Ercanoglu and Gokceoglu, 2004). A number of thematic maps (referred to as data layers in GIS) based on specific parameters or parameters which are related to the occurrence of landslides, viz. slope, aspect, lithology, distance to fault, distance to road, Distance from River, rainfall, and land cover have been generated (Fig 3). In this study, ILWIS v. 3.31 and ArcGIS v. 9.3 GIS software were used to produce the layer maps that assist in production of landslide susceptibility maps. Google earth imagery of the study area was used to digitize landslide, inventories and other features such as buildings, roads, etc. The coordinates of important point for geo reference point like road conjunction points and landslide prone area were measured during the field surveys using Global Positioning Systems (GPS) technology. In the measurement phase, one receiver served as a base station, while the other was used to collect GPS data at the selected ground control points. To establish relationship between object space and image space, ground control points were selected in the model area to conduct all measurements in the National Coordinate System. The digital elevation model (DEM) of the study area

was produced using from this model, maps showing slope, aspect, and distance from Rivers were obtained. Lithology and distance to fault maps were produced by evaluating geological maps that had been produced by intensively studying the field.



Fiure1: Location of the study area in India

3.1. Inventory map

The identification and mapping of existing landslides are prerequisite to perform statistical analysis on the relation between the distribution of landslides and influencing parameters (Saha et al. 2005). A Landslide Inventory Database of the study area was prepared by visual interpretation of Google Earth image, Landsat TM data of 1990 and 2010 years and field survey. The main scarp of every recorded landslide during the field work was depicted in

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topographic maps at a proper scale and then was digitized as polygon layer (Rozos et al. 2011). In the study area, there are 450 landslides from the inventory (Fig. 2). The areal extent of the smallest observable landslide is approximately 0.236 km2 and the largest is 3.957 km2. For each landslide in the inventory, it includes information such as location, size, and direction of the landslide, the bedrock, and surface material. A landslide scarp map (Fig. 2) was created and digitized based on the information provided in the landslide inventory and a surficial geology map. The scarp area is used instead of the whole landslide affected area in this study because it is difficult to determine the landslide affected area based on the available data (Fig.7).

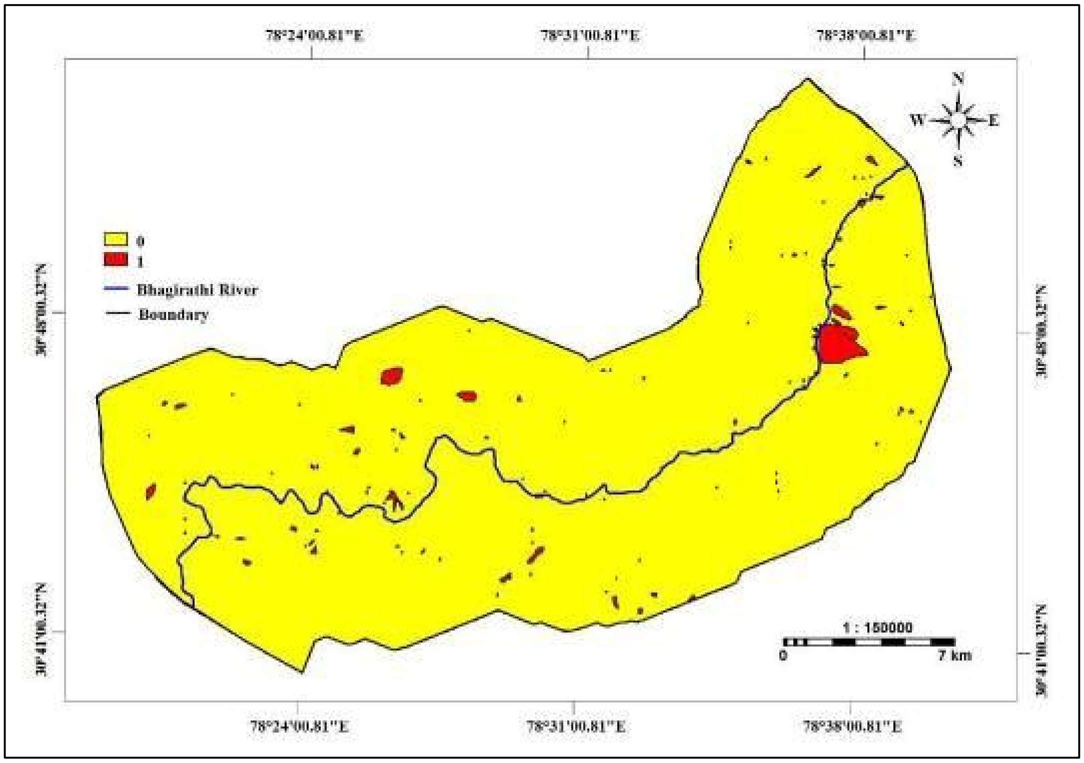

Figure 2: Landslide inventory map of Uttarkashi area

3.2. Data layer for factures influencing land slides

3.2.1. Slope

The slope angle was considered the main parameter of the slope stability (Lee and Min 2001); it was commonly used in preparing landslide susceptibility analyses (Anbalagan 1992; Pachauri et al. 1998; Saha et al. 2002; Yalcin 2008) as the shear stress increases with progressive inclination. Slope is the measure of surface steepness and measured in degrees. It has a range between 0_ and 90°, where 0° represents the flat and 90° represents the vertical areas. Slope angle is very frequently used in landslide susceptibility studies since landsliding is directly related to slope angle (Anbalagan 1992; Pachauri et al. 1998; Saha et al. 2002; Clerici et al. 2002). Landslides mostly occur at certain critical slope angles (Dai et al. 2001; Gokceoglu and Aksoy 1996; Uromeihy and Mahdavifar 2000; Lee and Min 2001; Cevik and Topal 2003; Fernandes et al., 2003). The slope values in the study area range between 0° and 75°. The slope of the study area was divided into six slope angle categories (Fig.7a) table indicates that most of the landslides occur at a slope angle of between 15-45 º with 78.42 percent of total landslide occurrence (Table 1).

3.2.2. Aspect

Like slope, aspect is one of the important factors in preparing landslide susceptibility maps (Carrara et al. 1999; Guzetti et al. 1999; Saha et al. 2002; Cevik and Topal 2003; Ercanoglu et al. 2004; Lee et al. 2004; Lee 2005; Yalcin 2008). Aspect related parameters such as exposure to sunlight, winds (dry or wet), rainfall (degree of saturation), soil moisture and discontinuities may control the occurrence of landslides (Gokceoglu and Aksoy 1996; Dai et al. 2001; Cevik and Topal 2003; Suzen and Doyuran, 2004 and Komac, 2006). In this study, the aspect map of the study area was produced to show the relationship between aspect and landslide. In the aspect map produced, aspect areas were classified into eight classes with the addition of flat areas as: flat (-1°), north (0°–22.5°), North-East (22.5°- 67.5°), east (67.5°–112.5°), South-East (112.5°-157.5°), south (157.5°–202.5°), South-West (202.5°-247.5°), west (247.5°–292.5°) and North-West (292.5°-337.5°) (Fig.7b).Some analyses were performed using aspect and landslide inventory map to determine the distribution of landslides, according to the aspect class of the table landslide occurred in the study area, 29.40 percent recorded in the West and 25.44 percent in North-West aspects classes respectively (Table 1).

Figure 3: Varnavat Pravat Landslide (Uttarkashi city) a: October 2012, b: September 2003

Figure 4: a: Maneri dam landslide, b: Laksheshwar landslide

Figure 5: a: Mala landslide, b: Dunda landslide

3.2.3. Rainfall

Rainfall is considered to be the most important landslide triggering parameter causing soil saturation and a rise in pore-water pressure. However, there are not many examples of the use of this parameter in stability zonation, probably due to the difficulty in collecting rainfall data for long periods over large areas. After interpolation between amounts of annual rainfall in the study area stations, the isohyets' map created. Finally this map has been grouped into five classes to prepare the rainfall data layer (Fig.7d). It was verified that approximately 57.99 percent of the landslides occurred in 1015-1020 mm class (Table 1).

3.2.4. Distance from river

An important parameter that controls the stability of a slope is the saturation degree of the material on the slope. The closeness of the slope to drainage structure is another important parameter in terms of stability. Streams may adversely affect stability by eroding the slopes or by saturating the lower part of material until resulting increase in water level (Cevik and Topal, 2003; Yalcin, 2005). A thorough field investigation should be carried out to determine the effects of streams on slope. Six different buffer areas were created within the study area to determine the degree to which the streams affected the slopes (Fig.7f). The landslide percentage in each buffer zone is given in Table 1 about 54 percent of the landslides are closely located within the 50-150 m and 150-300 m buffer zones (Table 1).

3.2.5. Distance from road

Similar to the effect of the distance to streams, landslides may also occur on the road and on the side of the slopes affected by roads (Pachauri and Pant, 1992; Pachauri et al., 1998; Ayalew and Yamagishi, 2005; Yalcin, 2005). A road constructed along slopes causes decrease in the load on both the topography and on the heel of the slope. Six different buffer areas were created on the path of the road to determine the effects of road on the stability of slope (Fig.7h). The landslide percentage in each buffer zone is given in Table 1 and shows that 65.93 percent of the landslides are closely located within the 300-600 m, 600-1000 m and 1000-1500 m buffer zones (table 1).

3.2.6. Distance from fault

The "distance to faults" layer has been created in order to take into account the probable seismic origin of the landslides (Demoulin and Chung (2007). A thorough field observation should be carried out to determine the effects of faults on the slope. Five different buffer areas were identified within the study area to determine the degree to which the faults affected the slopes (Fig.7g). The landslide percentage in each buffer zone is given in (Table 1) which shows that 34.19 percent of the landslides are closely located within the 4000-6000 m buffer zone.

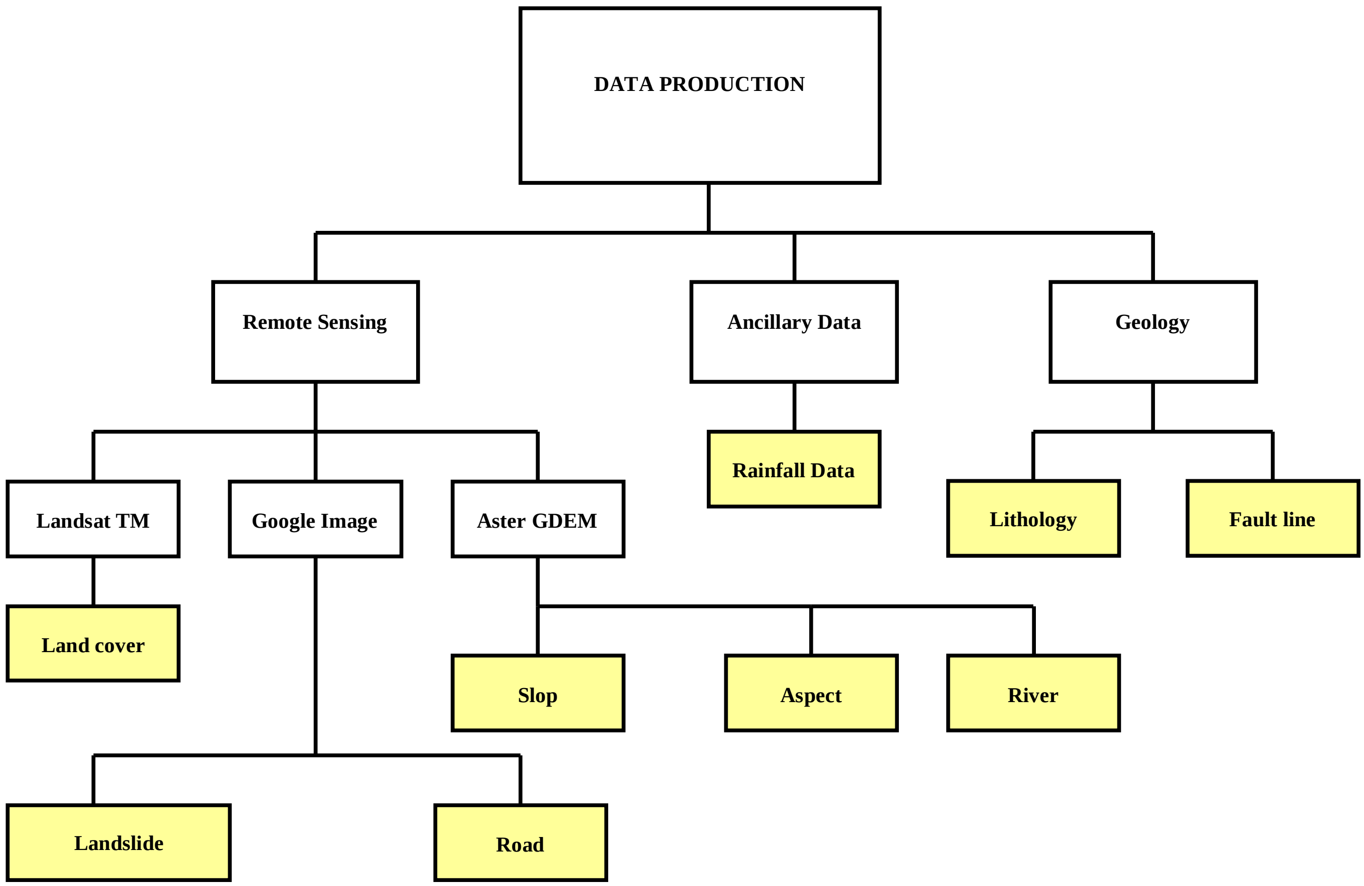

Figure 6: The elements and products of the study in data production stage

3.2.7. Land cover

Land use is also one of the key factors responsible for the occurrence of landslides, since, barren slopes are more prone to landslides. In contrast, vegetative areas tend to reduce the action of climatic agents such as rain, etc., thereby preventing the erosion due to the natural anchorage provided by the tree roots and, thus, are less prone to landslides (Gray and Leiser 1982; Dahal et.al 2008). Land cover map of the area has been prepared by Landsat TM of year 2010 by employing Erdas 9.3 and Ilwis 3.31 Softwares .Forest and agriculture are the main land cover classes in the study area. Coverage of natural vegetation is crucial in influencing slope stability due to better bonding of the slope material. Thus slopes with dense vegetation cover should be less prone to the occurrence of shallow landslides than barren slopes, while all other parameters remain constant (Fig.7e) Analyses has been made using land cover and landslide inventory maps to determine the distribution of landslides. According to the land cover classes, 86.58 percent of landslides occurred in dens and open forest area classes (Table 1).

3.2.8. Lithology

Lithology is a key parameter conditioning landslide occurrence because different lithologic units have different sensitivities to active geomorphological processes such as landslides (Carrara et al. 1991). Because of this, several researchers have used lithology as an input parameter to assess landslide susceptibility (Dai and Lee 2001; Cevik and Topal 2003; Suzen and Doyuran 2004a, b; Gokceoglu et al. 2005; Yalcin 2008; Lee and Pradhan 2007; Akgun et al. 2008)In present work, various rock formations of the study area have been grouped into nine classes for obtaining the lithological data layer. The nine classes correspond to (a) Amphibolites, (b) Granitic Gneisses, (c) Kot Metavolcanic, (d) Shyalna Limestone/ Dolomite, (e) Netala Quartzite, (f) Quartzite/Limston, (g) Epidiorite, (h)

Table1. Landslide database showing characteristics of the landslides

parameters	Class	Number of landslide pixels within the Class	Number of pixels in the Class	Landslide Area (%)	parameters	Class	Number of landslide pixels within the Class	Number of pixels in the Class	Landslide Area (%)
Inventory	Landslide	857	857	100.00	**Rainfall**	1000-1005 mm	39	5610	4.55
	No Landslide	0	64656	0.00		1005-1010 mm	222	22857	25.90
Aspect	FLAT	1	162	0.12		1010-1015 mm	78	14894	9.10
	NORTH	64	6726	7.47		1015-1020 mm	497	17406	57.99
	NORTH - EAST	79	8593	9.22		>1020 mm	21	4746	2.45
	EAST	53	8438	6.18	**Land cover**	Agriculture	30	6333	3.50
	SOUTH-EAST	45	7880	5.25		Open Forest	166	18866	19.37
	SOUTH	53	7709	6.18		Dens Forest	576	35143	67.21
	SOUTH-WEST	92	9257	10.74		Settlement	0	1317	0.00
	WEST	252	8724	29.40		River_stream	0	493	0.00
	NORTH-WEST	218	8024	25.44		Barren Land	85	3361	9.92
Distance from Fault	0-300 m	179	11368	20.89	**Slope**	0-5°	10	1599	1.17
	300-800 m	81	14422	9.45		5°-15°	39	6728	4.55
	800-1500 m	50	12063	5.83		15-25°	194	17244	22.64
	1500-2500 m	27	9358	3.15		25°-35°	227	18260	26.49
	2500-4000 m	162	6084	18.90		35°-45°	251	14889	29.29
	4000-6000 m	293	4566	34.19		>45°	136	6793	15.87
	>6000 m	65	7652	7.58	**Lithology**	Amphibolite	0	1899	0.00
Distance from River	0-50 m	140	10919	16.34		Granitic Gneisses	506	18731	59.04
	50-150 m	221	18632	25.79		Kot Metavolcanic	142	6576	16.57
	150-300 m	242	21821	28.24		Shyalna Limestone/ Dolomite	2	935	0.23
	300-500 m	190	11663	22.17		Netala Quartzite	33	3804	3.85
	500-1000 m	64	2434	7.47		Gamri Quartzite/Limston	142	24967	16.57
	>1000 m	0	44	0.00		Epidiorite	28	7382	3.27
Distance from Road	0-100 m	35	4335	4.08		Pujargaon Metavolcanics	1	1030	0.12
	100-300 m	75	5932	8.75		Sartali Slates	3	189	0.35
	300-600 m	178	6979	20.77					
	600-1000 m	175	8263	20.42					
	1000-1500 m	212	9136	24.74					
	1500-2500 m	126	14807	14.70					
	2500-4000 m	25	12476	2.92					
	>4000 m	31	3585	3.62					

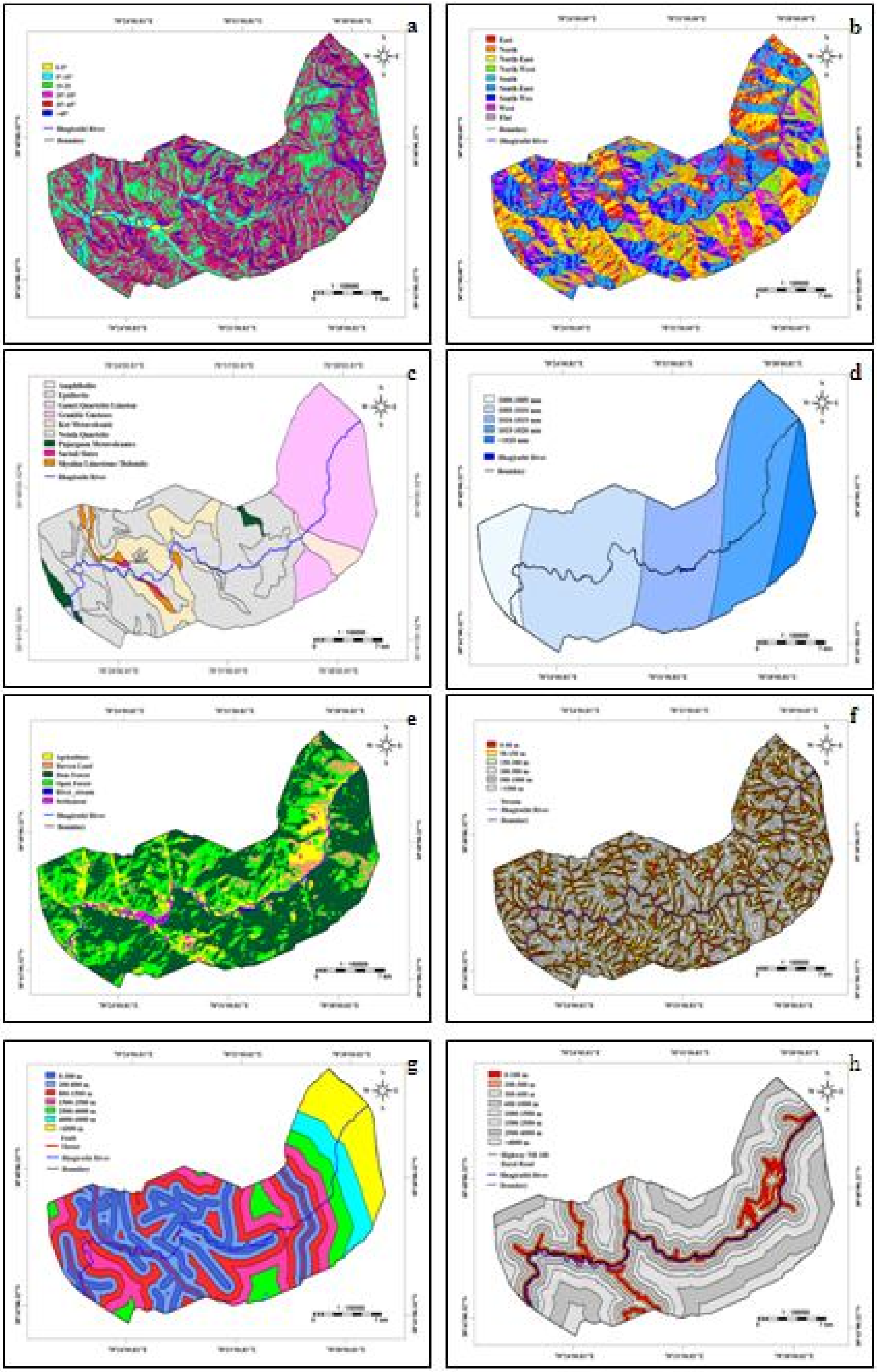

Figure 7: Input thematic layers of Uttarkashi area: (a) Slope gradient map, (b) Slope aspect map, (c) Lithology map, (d) Rainfall map, (e) Land cover map, (f) Distance from river map, (g) Distance from fault map, (h) Distance from road map

Pujargaon Metavolcanics, and (i) Sartali Slates (Fig.7c). The boundaries have been digitized from the geological map prepared by Agarwal and Kumar (1973). The landslide phenomenon, a part of the geomorphologic studies and research, is related to the lithology and weathering properties of the material of the land. It was verified and observed that 55.85percent of the landslides occurred in area dominated by shale rocks (Table 1).

3.3. Methodology

Influential parameters considered in this study for Landslide Susceptibility Zonation and of study area are: Slope(Sl),Aspect(As),Lithology (Li), Distance from fault (Dfa), Distance from road(Dro), Distance from river(Dri), Rainfall(Rf) and Land cover(Lc). These parameters have been used in different models to produce Landslide susceptibility map of the study area. These parameters have been used in *Multiple Linear Regression method* to produce Landslide susceptibility map of the study area. In order to carry out multivariate analysis of data and to determine the parameters responsible for landslides in the study area, a multiple linear regression has been used. The multiple linear regression method reveals that how the susceptibility of landslides changes as the standard deviation of independent variables and predictors change. Furthermore, it will help to make an equation and linear function (model) for landslide susceptibility in intended study area. In this study equation of the theoretical model will be described as follows.

$$L = B_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + ... + b_m X_m + \varepsilon \qquad \textit{(Eq.1)}$$

Where, L is the occurrence of landslides in each sampling unit, X's are the input independent variables (or instability parameters) observed for each mapping unit, the B's are coefficients estimated from the data through statistical techniques, and ε represents the model error (Irigaray *et al.*, 2007).

To produce landslide susceptibility map in this method, the amounts of quantitive and qualitive variables based on sampling of 80×80 m networks in form of a 65513×8 matrix have been transferred from GIS software (ILWIS 3.31) into statistical software (SPSS 20.0). To convert qualitive variables viz. lithology,

land cover and aspect into quantitive variables, the weight of each qualitive variable has been estimated from information value. Among 8 independent variables in *(Eq.1)* 6 variables including Lithology (*Li*), Aspect (*As*), , Distance to river (*Dro*) and Slope (*Sl*), Rainfall (*Rf)*, Land cover (*Lc*) have been accepted. After adding Land cover variable into the *(Eq.2)*, regression test gained 5% signification level and testing has been stopped.

$$L = (-.956) + (.005\, Li) + (.009\, As) + (-0.000006\, Dro) + (0.00033\, Sl) + (0.000326\, Rf) + (0.0059\, Lc) \qquad \textit{(Eq.2)}$$

Then calculated coefficients have been exerted in the matrix of dataset and the equation has been calculated for all of the 65513 sample pixels of the study area. Finally column of the equation result for analyzing and creating landslide susceptibility map has been transferred into GIS software (ILWIS 3.31).

After producing LSI map (fig. 9), by overlaying of inventory map and LSI map, a histogram (fig. 10), has been produced and then based on this histogram the LSZ map has been created (fig.11).

RESULTS AND DISCUSSION

The main goal of this study was to assessment and appraisal of the Multiple Linear Regression method in landslide susceptibility zonation and validation of landslide risk map with inventory map of the study area.

Result of Landslide hazard analysis has been validated using known landslide locations. Validation was performed by comparing the known landslide location data with the landslide hazard map (Fig. 2). Each factor used and multiple linear index result were compared. The rate curves were created, this curve, referred to as the success rate curve in the literature (Chung and Fabri, 1999, 2003; Lu and An, 1999; Remondo et al., 2003, Vijith et al. 2009, Pradhan and Lee 2010) is used to select the suitability of a particular LSZ map. The rate explains that how model and factors predict occurrence of landslide. The area under the curve may help in assessing prediction of landslides qualitatively. To obtain relative ranks for each prediction pattern, the calculated index values of all cells in the study area were average in descending order. Then the ordered cell values were divided into 100 classes with accumulated 1% intervals. The rate verification results appear as a line in (Fig. 12). In the Multiple Linear Regression method used, 90 percent to 100 percent (10%) class of the study area where the landslide index had a higher rank could explain 53 percent of all the landslides in the success rate and were classified as ‘‘very highly landslide’’ zone (Table 2). The next 70percent–100percent (30%) class of the study area where the landslide index has a higher rank could explain 68 percent of the landslides in the success rate and were classified as ‘‘highly

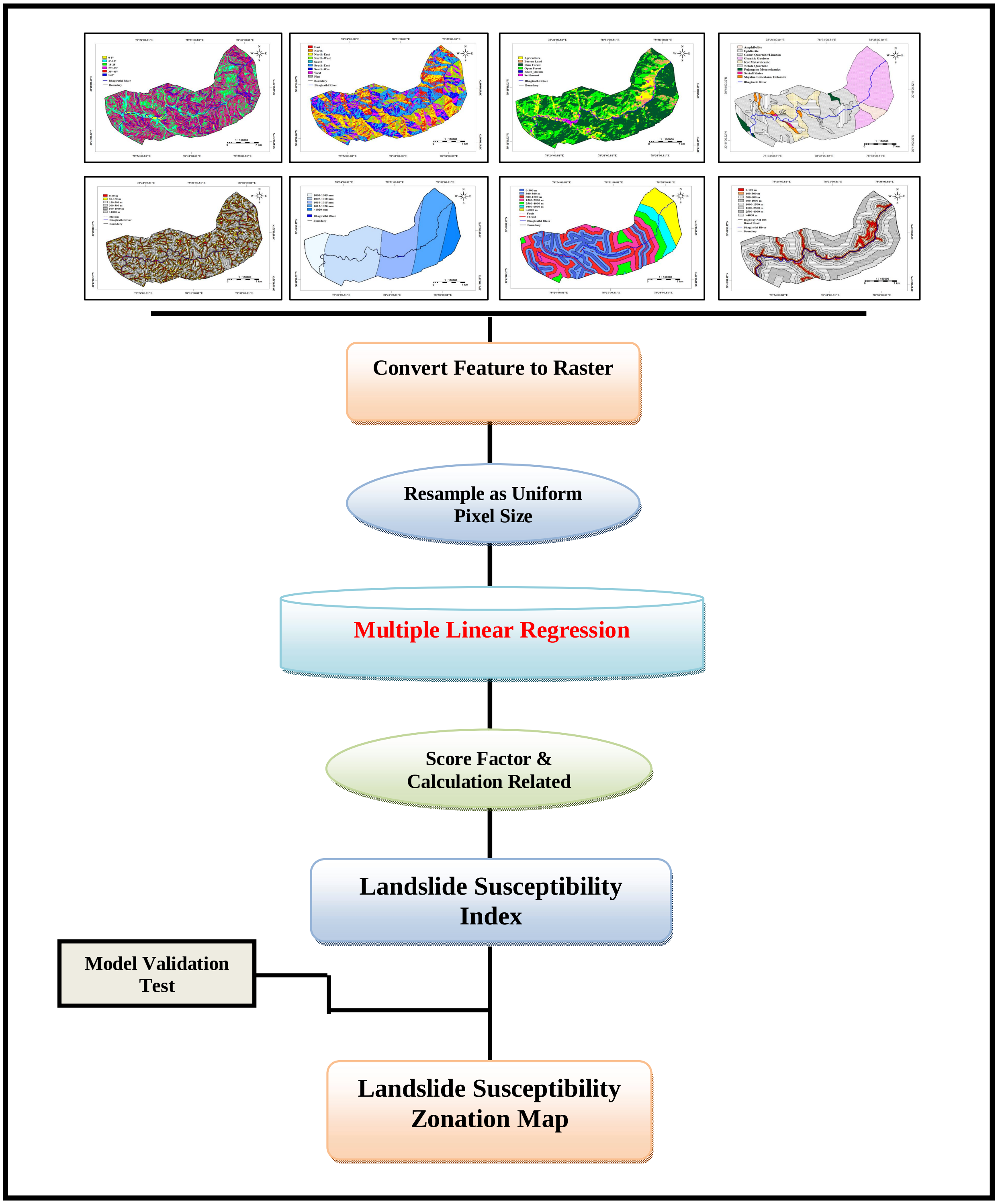

Figure 8: Schematic representation of preparation of LSZ map in Multiple Linear Regression model

landslide'' zone. Similarly, the 60percent–100percent (40%) class of the study area where the landslide index has a relatively lower rank could explain 72 percent of the landslides in the success rate and were classified as ''moderately landslide'' zone. Finally, the remaining 40percent–100percent (60%) class of the study area where the landslide index had a low rank could explain 82 percent of the landslides were classified as ''area with of landslide'' zone (Table 2). To compare the result quantitatively, the areas under the curve was recalculated as the total area is 1, which means perfect prediction accuracy. So, the area under a curve can be used to assess the prediction accuracy qualitatively. The area ratio calculated for Fig. 12, was 0.762 and it may be imbedded that the prediction accuracy is 76.2 percent (Table 3).

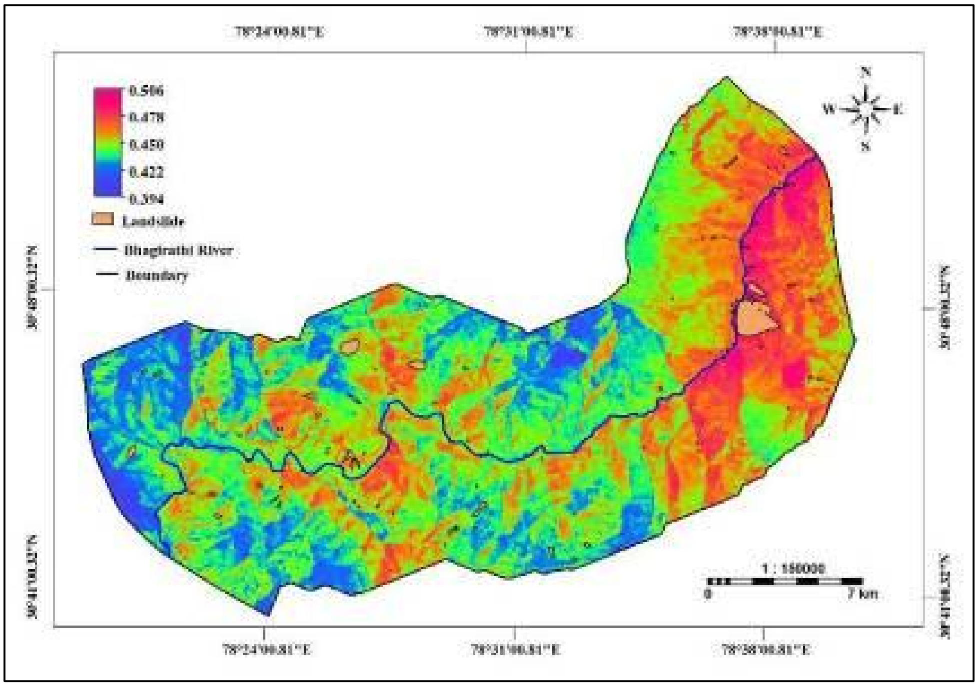

Figure 9: Landslide susceptibility Index (LSI) map

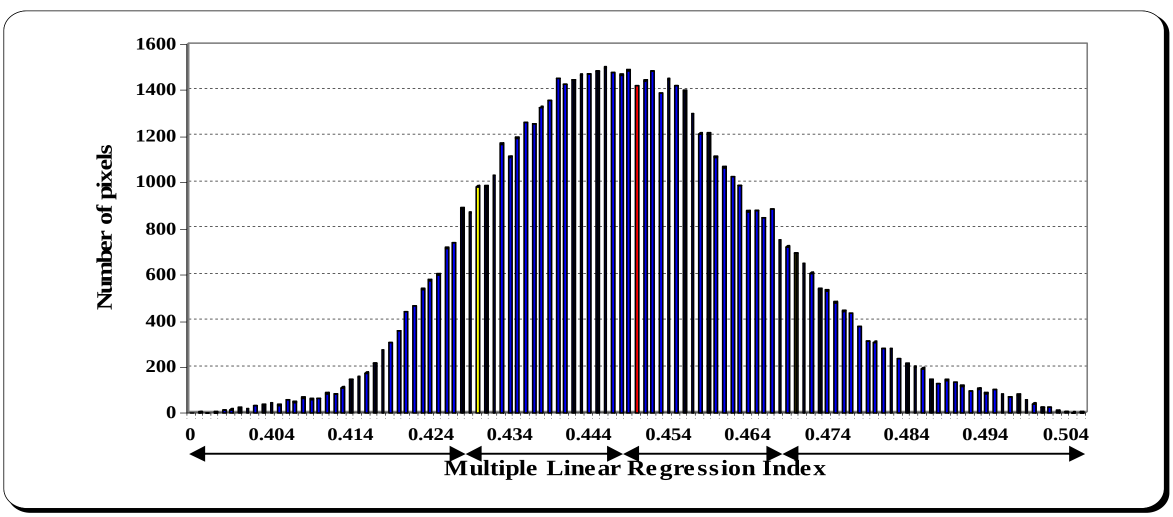

Figure 10: Distribution frequency histogram of landslide in the Multiple Linear Regression model

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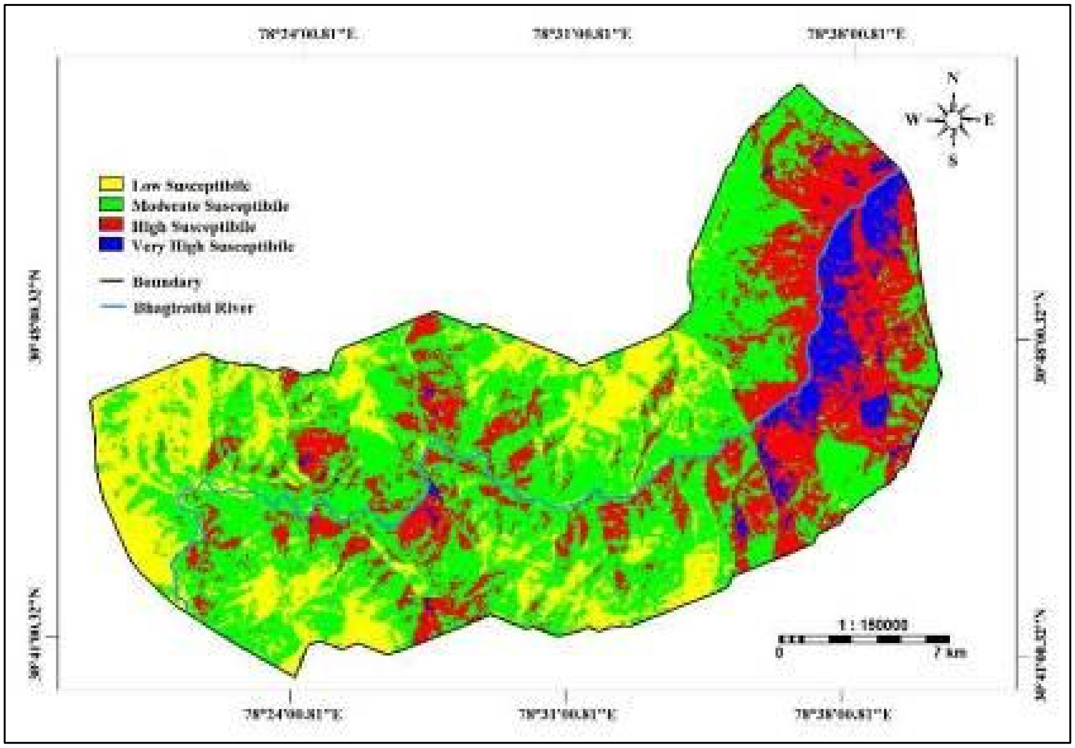

Figure11: Landslide susceptibility Zonation (LSZ) map

Table 2: Verification and success rate for the study Area

Range	Success rate curve (Heuristic)
100–100	**0**
90-100	**53**
80-100	**61**
70-100	**68**
60-100	**72**
50-100	**78**
40-100	**82**
30-100	**88**
20-100	**95**
10-100	**100**
0-100	**100**

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Table3: Verification results using area under ROC curve (AUC)

Area under the ROC curve (AUC)	**0.762**
Prediction accuracy (%)	**76.2**
Standard Error	**0.0096**
95% Confidence Interval	**0.758 to 0.765**
z statistic	**27.261**
Significance level P (Area=0.5)	**0.0001**

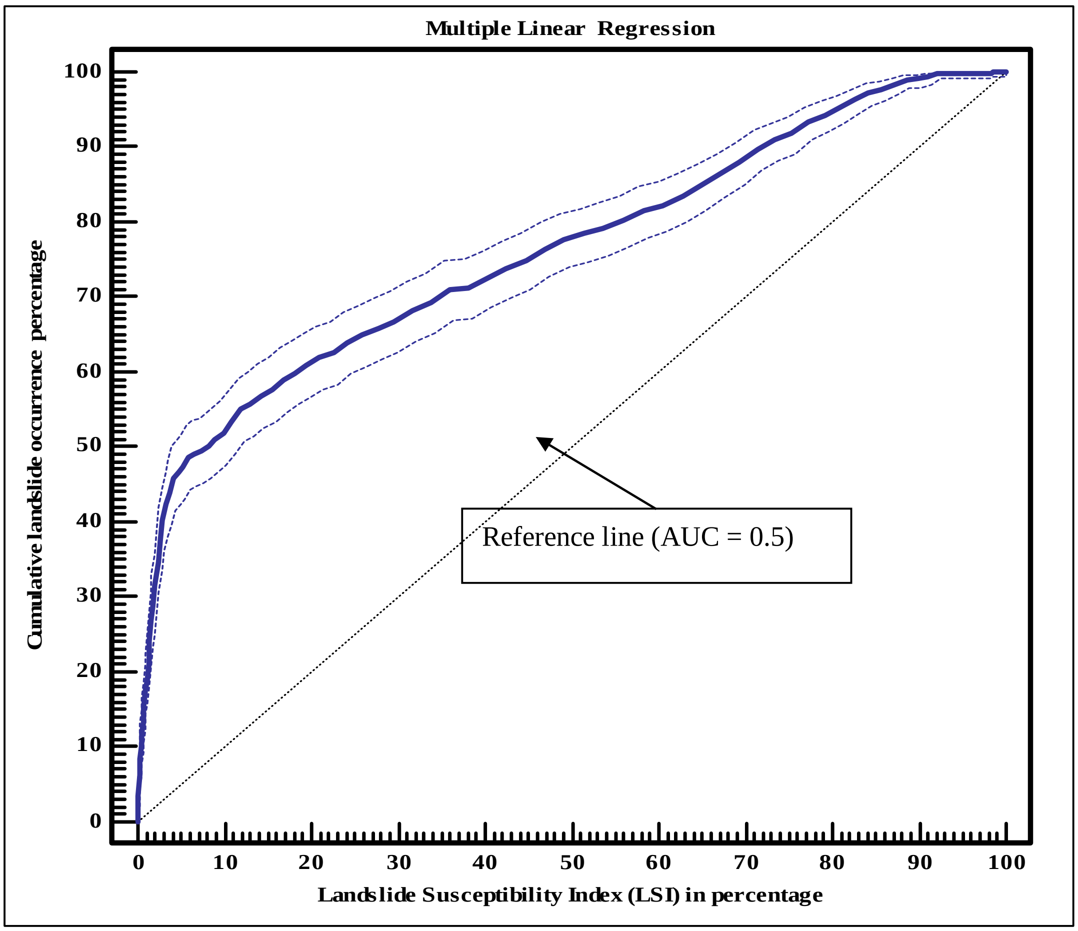

Figure 12: Cumulative frequency diagram showing success rate curve for susceptibility maps produced by Multiple Linear Regression model hazard map

After obtaining the susceptibility index map (Fig. 9), it is necessary to divide this map into different susceptibility classes. Generally, the most common method for this purpose depend on the optimum band width classification of the histograms of various parameters (Akgun and Bulut, 2007). In this study, we considered standard deviations classification system. According to the histogram of the multiple linear index dataset, it was found that standard deviation method is only suitable method for the present study to classify the index values. The histogram of the total cell distributions is shown in graph (Fig. 10) The standard deviation method has certain merit in that it uses the mean to generate class breaks, and allowed us to divide the landslide susceptibility index map into four categories of landslide susceptibility: low, moderate, high and very high (Table 4), by adding or subtracting one standard deviation at a time. As shown in Table 4 and Fig. 13, 20.58 percent of the study area is low susceptible. Moderate and High susceptible zones make up 49.28 percent and 25.33 percent respectively. The zone corresponding to very high susceptibility constitutes 4.81 percent (Fig. 13). On the basis of distribution of landslide inventory of the area, shows the validity of the system adopted to divide the landslide susceptibility index map.

Table 4: The areas of different landslide susceptibility zones based on the multiple linear regression method

Susceptible Class	Class ranges	Susceptible Area (Km^2)	Percentage of susceptibility classes	Percentage of landslide falling in susceptibility classes
Low Susceptible	0.394-0.434	86.30	20.58	5.60
Moderate Susceptible	0.435-0.457	206.61	49.28	27.54
High Susceptible	0.458-0.479	106.21	25.33	21.00
Very High Susceptible	0.480-0.506	20.15	4.81	45.86

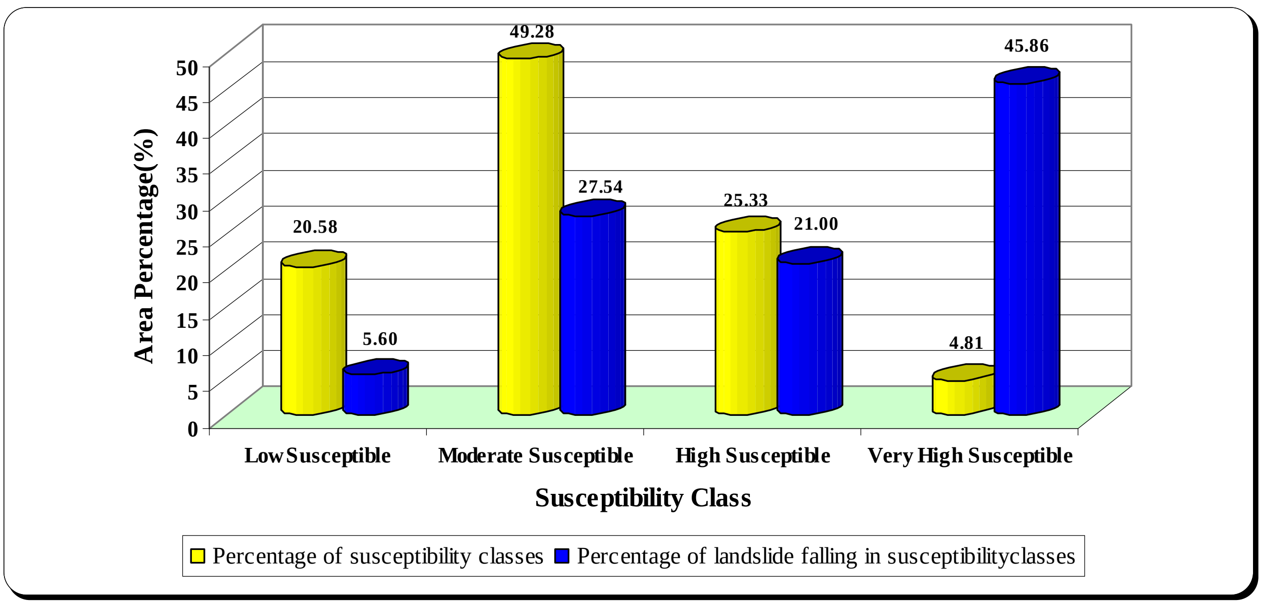

Figure13: Distribution of landslide frequency in landslide susceptibility zonation classes

Landslides in mountainous areas cause enormous loss of life and property every year. In such areas, landslide susceptibility mapping is very essential to delineate the landslide prone area. Various methodologies have been proposed for landslide susceptibility mappings, but in present case, the Multiple Linear Regression approach has been used because data acquisition and analysis are relatively easy and less time consuming. The modelling was applied in one small catchment area by considering eight predictive factors. The thematic layers of all predictive factors and existing landslides were prepared in GIS (ILWIS 3.31). Mainly DEM based derivates and field data were used to prepare data layers of predictive factors. In this study area, rainfall was the main triggering factor of landslides. As this study only deals with landslide susceptibility and not landslide hazard, information on the triggering factors of rainfall has not been taken into account in this modelling. From this study, the following conclusions were made.

- A Multiple Linear Regression model hazard map is able to predict 76.2 percent of all the landslides occurred in the study area. Thus, it could be concluded that Multiple Linear Regression approach could also useful in relatively moderate and small areas.
- This study also concludes that the approach of GIS based modelling can give good results in the analysis of field-oriented data.
- Landslide susceptibility index map of study area has classified into four categories of landslide susceptibility: low, moderate, high and very high, on the basis of distribution of landslide inventory of the area, shows the validity of the system adopted to divide the landslide susceptibility index map.
- Moreover, planning of any project at a local level requires large scale and more accurate landslide susceptibility mapping. Landslide susceptibility mapping at a small catchment scale covers a lot of information that is necessary for new level planning. On the basis of these landslides Susceptibility use of land different purposes may also be decided.

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