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# APPLICATION OF MULTIPLE LINEAR REGRESSION MODEL IN LANDSLIDE SUSCEPTIBILITY ZONATION MAPPING THE CASE STUDY NARMAB BASIN IRAN

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## ABSTRACT

Landslide is a form of slope process which points to the transmission and downward movement of materials, such as soil and rock mass. Every year landslide takes a heavy death-toll and damage to property. It also becomes difficult to provide instant relief measure. For the present study, *Narmab* basin has been selected which is situated in the southern part of Minūdasht Township in *Golestan* province of Iran.

The most affected villages are *Nishak, Saran* and *Takht*. The populations living in these villages suffer badly from the onslaught of landslide. Therefore, landslide susceptibility mapping is one of the important issues for urban and rural planning in Iran.

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 and distance from fault, distance from river, and distance from road were used as variables in the Multiple Linear Regression analysis. Ilwis 3.3 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 is 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 (79.7%) shows high prediction accuracy. The study area has been classified into five classes of relative landslide susceptibility, namely, Very Low, Low, Moderate, High, and Very High.

Key Words: Iran, basin, Landslide Susceptibility Zonation, Multiple Linear Regression method, AUC

## **INTRODUCTION**

Landslides are amongst the most damaging natural hazards in the mountainous terrain such as the Alborz. The study of landslides has drawn worldwide attention mainly due to increasing awareness of the socioeconomic impacts of landslides (Aleotti and Chowdhury, 1999).

For many natural and anthropogenic reasons, northern slopes of Alborz Mountain in Iran are at the risk of a number of small and large-scale landslides which take their heavy tolls in this area. For instance in Alborz mountain Iran, Manjil landslide in 1990, Abask landslide in 1993, Kiasar landslide in 1999, Karaj-Chalous road's landslide in 2007, Hezarcham landslide in 2007 are major landslides Nishak, Saran and Takht villages which are situated in Narmab basin, are destroyed completely or they face to the risk of landslide. 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 Iran.

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 modeling. 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

## **Research Article**

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), Eshlaghi Frahani (2001), Die and Lee (2002), Ayalew and Yamagishi (2005), Chen and Wang (2007).

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. Further, Rezaei Moghaddam et al (2007) considered parameters like lithology, elevation, slope gradient, lineaments and the distance from streams, vegetation, and land use for landslide zonation of Merek area of Iran. In this study, factors such as slope gradient, slope aspect, geology, land-use, precipitation, proximity to fault, proximity to river, proximity to road and altitude have been used for modeling 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 method in landslide susceptibility zonation and validation of landslide susceptibility map with inventory map of study area.

#### Study area

The study area occupies about 218.53 Km<sup>2</sup> in the East of Northern Alborz located in South Eastern part of Golestan province (Figure 1). The terrain is highly rugged with elevations ranging from about 150 to 2060 m above the mean sea level.



### Figure 1: Location of the study area in Iran

The Narmab River flows through the southern part of the study area and its tributaries constitute the drainage network in the area. Structurally, the region is complex due to presence of various thrusts, faults and intense deformations. The area has experienced numerous landslides of different dimensions causing damage to human life and property.

#### MATERIALS AND METHODS

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). 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 (Figure 2). In this study, Ilwis v. 3.3 and Arc GIS 9.3 GIS and Global Mapper 13.0 GIS software's were used to produce the layer maps that assist in production of landslide susceptibility maps. Google earth imagery and National Geographic Organization topographic maps on a scale of 1:50,000 of the study area were used to digitize landslide, land cover types, boundaries 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.



Figure 2: Pasposhteh1 Landslide (Source: Google)

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 vector maps were produced from the Google Earth images using occurrences of the previous landslides, buildings, roads, land cover boundaries, and other important features. Therefore, landslide and land cover change detection may be effectively determined using Google Earth imagery. The digital elevation model (DEM) of the study area was produced using topographic maps on a scale of 1/50,000. 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. Also, landslide inventory maps and land cover maps were produced by evaluating Google earth images and field check to realization of satellite images. As a result, the relationships between the subgroups of the layer and landslide were shown using landslide inventory maps of the obtained data layers.

## 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). Landslide prone areas were detected in the Narmab area by visual interpretation of Google Earth Images and field surveys. A map of recent landslides was developed from 1:20 000 scale aerial photographs, and this was used to evaluate frequency and distribution of shallow landslides in the area (Figure 7).

## Data layer for factures influencing land slides

#### Slope

The main parameter of slope stability analysis is the slope angle. The slope angle is directly related to occurrences of landslides, it is frequently used in preparing landslide susceptibility maps (Yalcin, 2008). The slope of the study area has been divided into six slope categories. By use Ilwis 3.3 analysis rate of occurrences of landslides in a slope group the particular slope category has been observed (table.1) table indicates that most of the landslides occur at a slope angle of between 5-25 ° with 88.54percent of total landslide occurrence (Figure 7).



Figure 3: Sasang Landslide



Figure 4: Pasposhteh2 Landslide



Figure 5: Sasang landslide (Source: Google)

#### Aspect

Like slope, aspect is one of the important factors in preparing landslide susceptibility maps (Van Westen and Bonilla 1990; Carrara *et al.*, 1999; Maharaj 1993; Guzetti *et al.*, 1999; Nagarajan *et al.*, 2000; Saha *et al.*, 2002; Cevik and Topal 2003; Ercanog'lu *et al.*, 2004; Lee *et al.*, 2004a; Lee 2005). Aspect related parameters such as exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities may control the occurrence of landslides (Gokceoglu and Aksoy 1996; Dai *et al.*, 2001; Cevik and Topal 2003; Suzen and Doyuran, 2004and Komac, 2006). In this study, the aspect map of the study area was produced to show the relationship between aspect and landslide. Aspect regions are classified according to the aspect class as flat, 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°) (Figure 7).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 area percent, 19.81 recorded in the West and 19.57 percent in South-West aspects classes respectively (Table 1).

## **Research Article**

### 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 (Figure 7). It was verified that approximately 34.37 percent of the landslides occurred in 850-900M class (Table 1).



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

#### 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 (Figure 7). The landslide percentage in each buffer zone is given in Table 1 about 29.36precent of the landslides are closely located within the 150-300 m buffer zone (Table 1).

#### 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 (Figure 7). The landslide percentage in each buffer zone is given in Table 1 and shows that 35.32percent of the landslides are closely located within the 500-1000 m buffer zone (table 1).

## **Research Article**

Table1: Landslide database s	howing cha	racteristics of	the landslides
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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	419	419	100.00	Rainfall	600< mm	0	1044	0.00
	No Landslide	0	21414	0.00		600-650 mm	0	1086	0.00
Aspect	FLAT	8	838	1.91		650-700 mm	13	1060	3.10
	NORTH	9	1454	2.15		700-750 mm	85	1002	20.29
	NORTH - EAST	23	3439	5.49		750-800 mm	34	2088	8.11
	EAST	21	2112	5.01		800-850 mm	109	7485	26.01
	SOUTH-EAST	50	1414	11.93		850-900 mm	144	7341	34.37
	SOUTH	65	982	15.51		900> mm	34	727	8.11
	SOUTH-WEST	82	3025	19.57	Land cover	Agriculture	161	4599	38.42
	WEST	83	3962	19.81		Open Forest	124	9042	29.59
	NORTH-WEST	78	4607	18.62		Dense Forest	105	6947	25.06
Distance from Fault	0-50 m	27	1840	6.44		Fallow Land	12	415	2.86
	50-150 m	44	3130	10.50		Barren Land	13	459	3.10
	150-300 m	44	4106	10.50		River Stream	2	212	0.48
	300-500 m	95	4262	22.67		Settlement	2	159	0.48
	500-1200 m	197	6532	47.02	Slope	0-5 °	12	1789	2.86
	>1200 m	12	1963	2.86		5-15 °	208	8090	49.64
Distance from River	0-50	51	2211	12.17		15-25 °	163	8674	38.90
	50-150 m	90	3892	21.48		25-35°	36	2773	8.59
	150-300 m	123	5191	29.36		35-45°	0	456	0.00
	300-500 m	69	4601	16.47		>45 °	0	51	0.00
	500-1000 m	59	4803	14.08	Lithology	Flovial	9	1207	2.15
	>1000 m	27	1135	6.44		Sandstone	111	3722	26.49
Distance from Road	0-50 m	26	736	6.21		Limstone	32	4693	7.64
	50-150 m	44	1330	10.50		Basalt	27	566	6.44
	150-300 m	85	1906	20.29		Shail	234	11097	55.85
	300-500 m	82	2138	19.57		Quartzite	6	548	1.43
	500-1000 m	148	4522	35.32					
	>1000 m	34	11201	8.11					



## **Research Article**



**Figure 7: Input data layers of Narmab area:** (a) slope aspect map, (b) Slope gradient map, (c) Distance from fault map, (d) Lithology map, (e) distance from road map, (f) Distance from stream map, (g) Rainfall, (h) Land cover map

## **Research Article**

#### Methodology

Influential parameters considered in this study for Landslide Susceptibility Zonation and of study area are: Slope(Sl), Aspect(As), Lithology (Li), Distance to fault (Dfa), Distance to road(Dro), Distance from River(Dri), Rainfall(Rf) and Land cover(Lc) (Figure 7,8). 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.

$$L = B_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \dots + b_m X_m + \varepsilon$$
 (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  $\varepsilon$  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  $50\times50$  networks in form of a  $21833\times9$  matrix have been transferred from GIS software (ILWIS 3.3) into statistical software (SPSS). To convert qualitive variables viz. lithology, landcover and aspect into quantitive variables, the weight of each qualitive variable has been estimated from information value. Among 8 independent variables in (Eq.1) 5 variables including Landcover (*Lc*), Aspect (*As*), Lithology (*Li*), Distance to river (*Dri*) and Slope (*SI*) have been accepted. After adding slope variable into the (Eq.2), regression test gained 5% signification level and testing has been stopped.

L = .01840 + (.1577 Lc) + (.03061 As) + (.01067 Li) + (.000007153 Dri) + (.0001831 Sl) (Eq.2)

Then calculated coefficients have been exerted in the matrix of dataset and the equation has been calculated for all of the 3498 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 3.3).

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

### **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 (Figure 9). Each factor used and frequency ratio 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 (Table 2). In the Multiple Linear Regression method used, 90percent to 100 percent(10%) class of the study area where the landslide index had a higher rank could explain 33 percent of all the landslides in the success rate and were classified as "very highly landslide" zone. The next 70 percent-100percent (30%) class of the study area where the landslide index has a higher rank could explain 79 percent of the landslides in the success rate and were classified as "highly landslide" zone. Similarly, the 60percent-100percent (40%) class of the study area where the landslide index has a relatively lower rank could explain 90

## **Research Article**

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 95percentof the landslides were classified as "area with of landslide" zone. 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 Figure 11 was 0.797 and it may be imbedded that the prediction accuracy is 79.7 percent (Table 3).



# 55-29'01.00°E 55'34'01.00'E 55729793.00°E 55'24'01.00"E #118 00 B0.10 L'ADDRAFTE 0.00.000 Legen Lege 02813 0.01588 0.00363 1.03311 55'24'01.09"E \$5'34'91.00"E 55'20'01.00"E 55'20'01.00'E



model

Figure 9: Multiple Linear Regression LSI mapFigure 10: Multiple Linear Regression LSZmap



Figure11: Distribution frequency histogram of landslide in the Multiple Linear Regression model

**Research Article** 

Range	Success rate curve		
100-100	0		
90-100	33		
80-100	52		
70-100	79		
60-100	90		
50-100	93		
40-100	95		
30-100	98		
20-100	99		
10-100	100		
0-100	100		

Table 2: Verification and success rate for the study Area

Table 3: Verification results using area under curve (AUC)

Area under the ROC curve (AUC)	0.797
Prediction accuracy (%)	79.7
Standard Error	0.0131
95% Confidence Interval	0.792 to 0.803
z statistic	22.640
Significance level P (Area=0.5)	0.0001

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 method 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 3.3). 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 79.7 percent of all the landslides occurred in the study area. Thus, it could be concluded that Multiple Linear Regression method could also useful in relatively smaller catchments.

This study also concludes that the approach of GIS based modelling can give good results in the analysis of field-oriented data.





Figure11: Prediction accuracy assessment and success rate curve for Multiple Linear Regression model hazard 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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