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A GIS-based statistical model for landslide susceptibility mapping: A case study in the Taleghan watershed, Iran

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ABSTRACT: Preparation of landslide susceptibility map is the first step for landslide hazard mitigation and risk assessment. The main aim of this study is to identify areas prone to landslides in Taleghan watershed in Iran. For this purpose, thematic maps of twelve effective factors on landslide, including altitude, slope angle, aspect, plan curvature, rainfall, temperature, land-use, vegetation density, lithology, distance from faults, distance from rivers and distance from roads, are prepared by use of topographic maps, geological maps, geographic information system (GIS), aerial photographs, Satellite images and field study. In order to quantifying the parameters in the form of weighting factors, the coverage of landslides in different observation was determined. The relationship between the factors and the landslides were calculated using multiple regression analysis; The Stepwise method was used for statistical analysis. Result showed that Lithology, distance from the river, distance from roads, elevation, land-use, distance from fault and slope angle, are as most effective factors in landslide respectively. Finally, using the regression model and GIS tools, landslides Susceptibility Mapping has been prepared and study area has been categorized as very low, low, medium, high and very high susceptibility.

Keywords: landslides, susceptibility mapping, Multiple Regression, GIS, Taleghan

INTRODUCTION

Landslide is a natural disaster that can result in enormous property damages and human casualties. In many countries, the economic losses and causalities due to landslides are greater than commonly recognized and generate a yearly loss of property larger than that from any other natural disaster, including earthquakes, floods and volcanoes (Ayalew *et al.,* 2004). Landslide susceptibility maps are important tools for planning future developmental activities.

The aim of the landslide susceptibility mapping is to identify areas that are susceptible to future landslides, based on the knowledge of past landslide events and terrain parameters, geological attributes and other possibly anthropogenic environmental conditions that are associated with the presence or absence of such phenomena. During the recent decades, the use of landslide susceptibility maps for land use planning has increased significantly. These maps rank different sections of land surface according to the degree of actual or potential landslide hazard; thus, planners are able to choose favorable sites for urban and rural development. In recent years, the use of GIS for landslide hazard modeling has been increasingly used. It is because of the development of commercial systems and the quick access to data obtained through Global Positioning System (GPS) and remote sensing. Moreover, GIS is an excellent and useful tool for the spatial analysis of a multi-dimensional phenomenon such as landslides and for the landslide susceptibility mapping (Boroushaki and Malczewski 2008, Carrara *et al.,* 1999, Cevik and Topal 2003).

Landslide susceptibility can be determined by using comparative analyses of conditions and factors in previously damaged areas. Major parameters that often involved in modeling landslide susceptibility are topography (elevation, slope angle, aspect and plan curvature), climate (rainfall and temperature), geology (lithology and distance from fault), soil properties, morphometric features, erosion, distance from road, river network, land-use and vegetation density (Chung *et al.,* 1995, Guzzetti *et al.,* 2012, Lan *et al.,* 2004, Lee and Pradhan 2007, Lee and Ryu 2004, Motamedvaziri *et al.,* 2015).

Various methods and techniques have been proposed for mapping landslide susceptibility, such as multiple regression analysis, analytical hierarchy process, artificial neural network, neuro-fuzzy, decision tree, and support vector machines (Lan *et al.,* 2004, Pachauri *et al.,* 1998, Pourghasemi *et al.,* 2013).

During the past decades, many GIS-based approaches have been conducted for quantitative prediction of landslide (Saha *et al.,* 2005). It is also common to use multivariate statistics with GIS tools in landslide susceptibility studies (Boroushaki and Malczewski 2008). From multivariate analysis, better hypothetical correlation between instability factors and landslide occurrence is perceived and it provides more reliable response (Lee and Pradhan 2007).

Multiple regression analysis plays a central role in statistics that cause one of the most powerful and commonly used techniques.

In this study, a GIS based Multiple Regression Model was used for landslide susceptibility mapping at Taleghan watershed in Iran.

MATERIALS AND METHODS

A. Study area

Taleghan watershed covering 1243 km^2 is located in Alborz province. This watershed is geographically located between 50°45'00" to 51°11'15" E longitudes and 36°5'20" to 36°11'15" N latitudes (Fig. 1). The altitude of the area ranges from 1260 to 4380 m above the sea level. The weighted average slope is 33.6%. The mean annual rainfall is from 329 to 1278 mm and the mean annual temperature is 11.4 °C. In This Watershed, More than 31 geologic groups and units are recognized.

B. Methodology

Preparation of landslides inventory map. Preparation of a landslides inventory map is considered as the first step in landslide susceptibility assessment. Accurate detection of the location of landslides is very important to analyze landslide hazard. The landslide inventory map shows the noticeable landslides on the land (Lan *et al.*, 2004, Motamedvaziri *et al.*, 2015, Schuster and Fleming 1986). In order to generating landslide inventory map, first the locations and types of landslides were recognized using satellite image and aerial photograph, and marked on the photos. Then all of the marked areas on the photos were controlled with field observations and questionnaire complementing. For providing the landslides Inventory map, using GPS, The exact location of landslides was determined and entered to Arc-GIS software (Fig. 2).

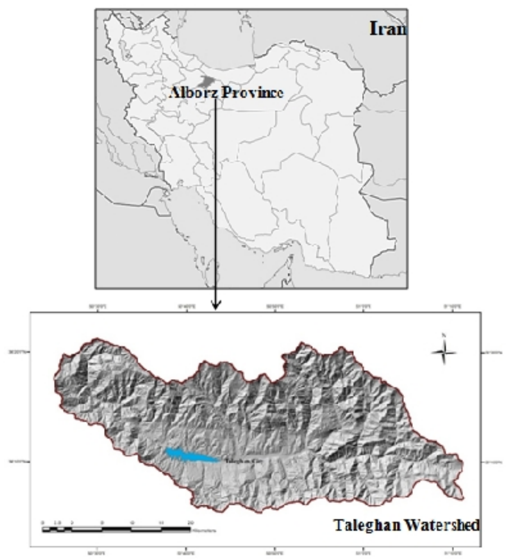


Fig. 1. The Location of Taleghan watershed in Iran.

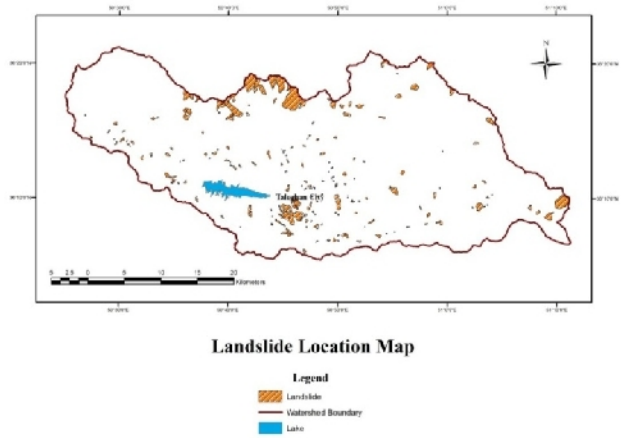


Fig. 2. Landslides distribution map of study area.

Preparation of landslides effective factors maps. In this study, a total twelve landslide conditioning factors were selected based on the analysis of the landslide inventory map. They are altitude, slope angle, aspect, plan curvature, rainfall, temperature, land-use, vegetation density, lithology, distance from faults, distance from rivers and distance from roads.

A digital elevation model (DEM) for the study area was generated from the topographic maps at a scale of 1:25,000. Based on the DEM, slope, altitude, aspect and plan curvature were extracted. Rainfall and temperature data were extracted from a database from the meteorological stations of study area. These data were used to create the rainfall map and temperature map using inverse distance weighted method. The land-use map in the study area was generated from Landsat 7 ETM+ satellite imagesand field observations. The vegetation density map (based on NDVI map) was obtained also from the aforementioned Landsat 7 ETM+ satellite images. Lithology map was extracted from geological map of taleghan watershed at scale 1:100 000. Fault lines map was extracted from geological map of taleghan watershed at scale 1:100 000 and used to construct the distance from fault map. Road and river networks were extracted from the topographic map at a scale of 1:25,000 and used to construct the distance from road maps and the distance from river maps respectively (Fig. 3 to 5).

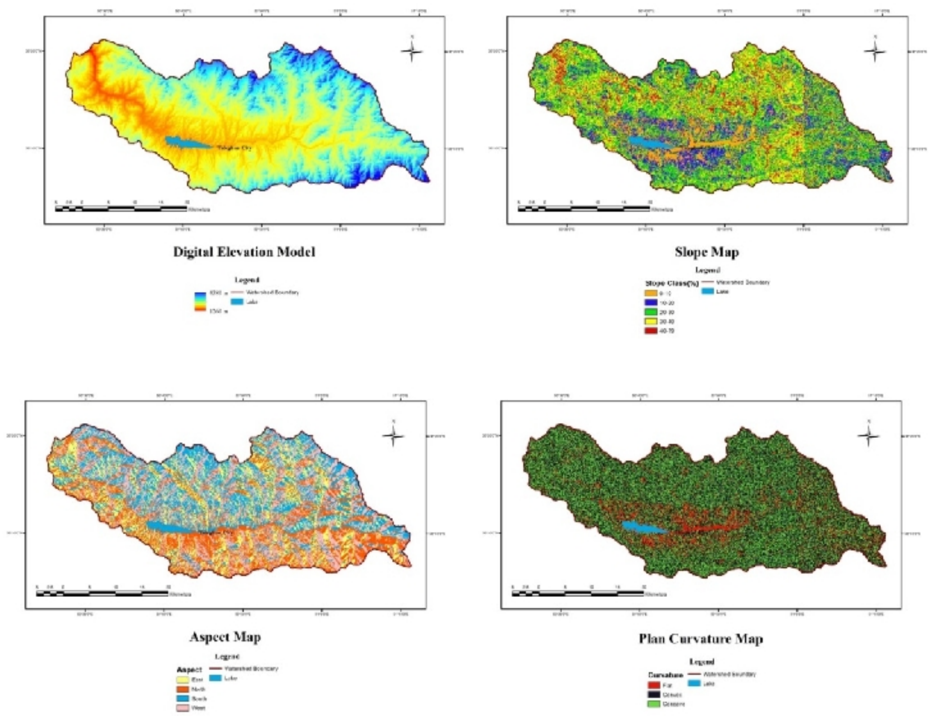
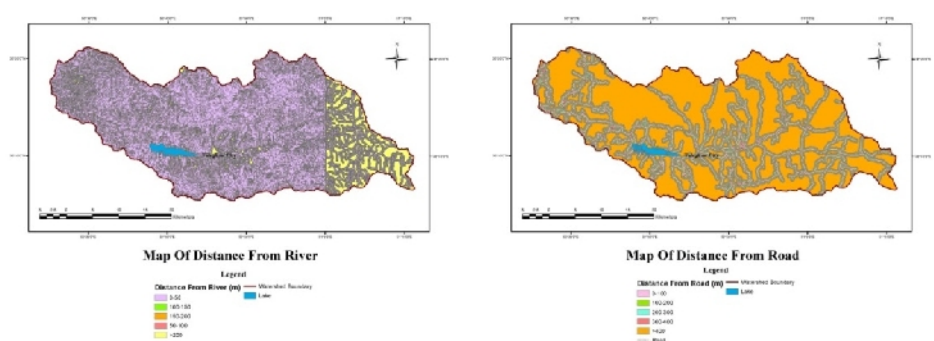


Fig. 3. DEM, slope, aspect and plan curvature maps of study area.



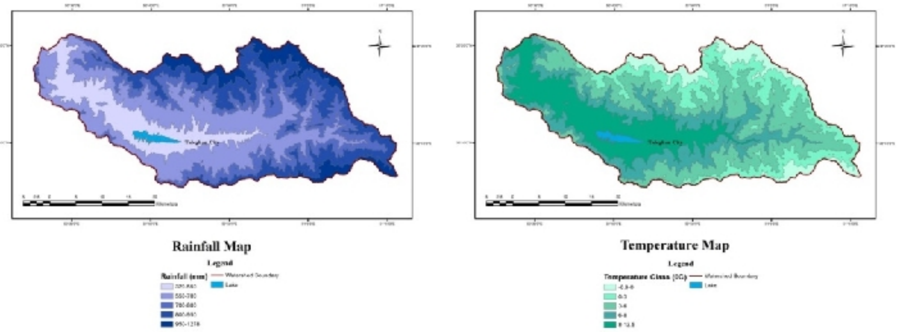


Fig. 4. Distance from river, distance from road, and temperature and rainfall maps of study area.

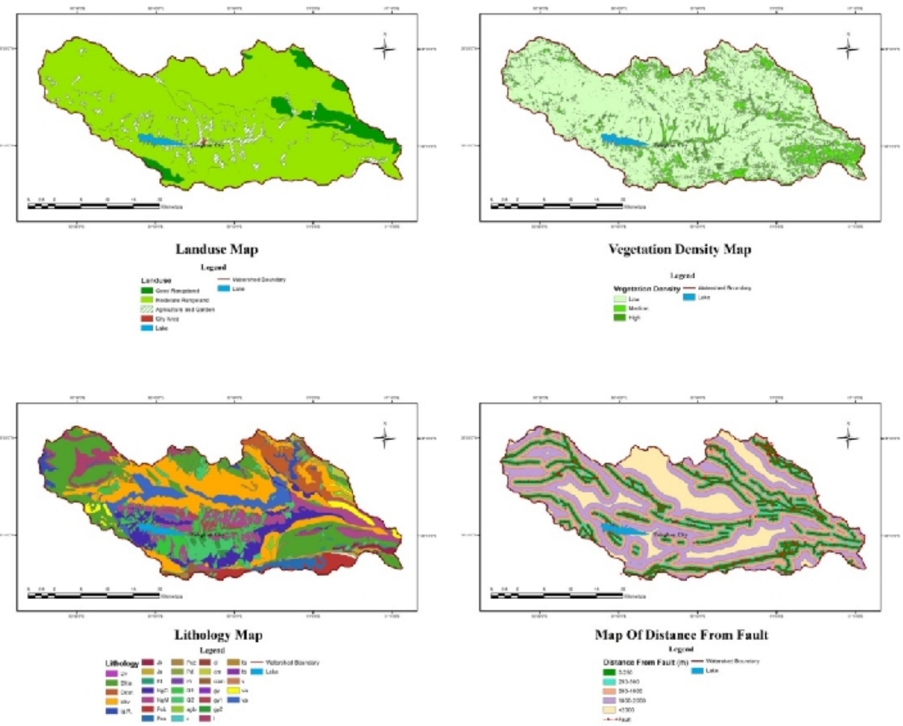


Fig. 5. Vegetation density, land-use, lithology and distance from fault maps of study area.

Preparation of homogenous units map. Homogenous units (units with similar characteristics) map were generated using effective factors layers. Homogeneous units were identified by combining the data layers which representing the effective parameters. To produce the homogenous, all of the layers were overlaid. Finally 175 homogeneous unites were identified.

Quantifying the effective parameters and weighting the factors. Before modeling, the classified factors should be weighted. Quantifying the effective parameters and weighting the factors was based on the area percentage of landslides in the homogenous units where all of the effective parameters were similar excluding one of them that was changing. The area percentage of landslides which depended on each factors were identified by calculating the ratio of observed landslide area to the area of homogeneous units. The weight factor for each class of a specific factor was produced by summing the ratios for each class in different units.

Weight factors were transferred to the quantitative values from 0 to 1. The class with maximum of the area percentage summation was given the weight of 1 and other classes were given below (<1) based on their proportions.

Modeling landslide susceptibility using multivariate statistical analysis. Linear regression is a form of multivariate statistical analysis in which observational data are modeled by a function. The function has usually assumed one response variable Y and m predictor variables $X_1, X_2, \ldots, X_m$ and n observations.

Y is the area percentage of landslides in each homogenous unit, the X's are input independent variables (the weight of classes in effective factors) measured or observed for n homogeneous unit [15].
In this study, Multivariate statistical analysis employed to generate multivariate regression model using SPSS software. Derived model was applied to calculated landslide susceptibility map in a raster environment. Raster map was classified into five quantitative classes range from very low to very high.

RESULTS AND DISCUSSION

According to the inventory map, there were 228 landslide events in the study area that had an area about 46.28 km2.
After preparation of landslides effective factors maps and homogenous units map, and then quantifying the effective parameters and weighting the factors, these data were moved into SPSS software environment.
Multivariate regressions with stepwise method in SPSS software was used with twelve factors including altitude, slope, aspect, plan curvature, rainfall, temperature, land-use, vegetation density, lithology, distance from faults, distance from rivers and distance from roads, against 175 homogeneous units. In this method, independent variables (effective factors) were entered based on its correlation with depend variable (landslide susceptibility). Variables with greater correlation are entered earlier and variables with lower correlation are eliminated. With regard to the results of multiple regression analysis, Lithology, distance from the river, distance from roads, elevation, land-use, distance from fault and slope angle, were significant. Eventually a numerical model of landslide susceptibility zonation is formed as follow:
$Y = 0287X1 - 0.276X2 - 0.188X3 + 0.133X4 - 0.06X5 + 0.04X6 + 0.03X7 - 0.125$
Where: Y is landslide susceptibility coefficient , X1 is lithology factor , X2 is distance from river factor , X3 is distance from road factor , X4 is factor elevation , X5 is Land-use factor, X6 is distance from fault factor, And X7 is slope factor.
Derived multiple regression model was applied on theme maps in Arc-GIS software environment. After overlying theme maps with regards to coefficients of derived model, landslide hazard zonation map of Taleghan watershed was prepared (Fig. 6).

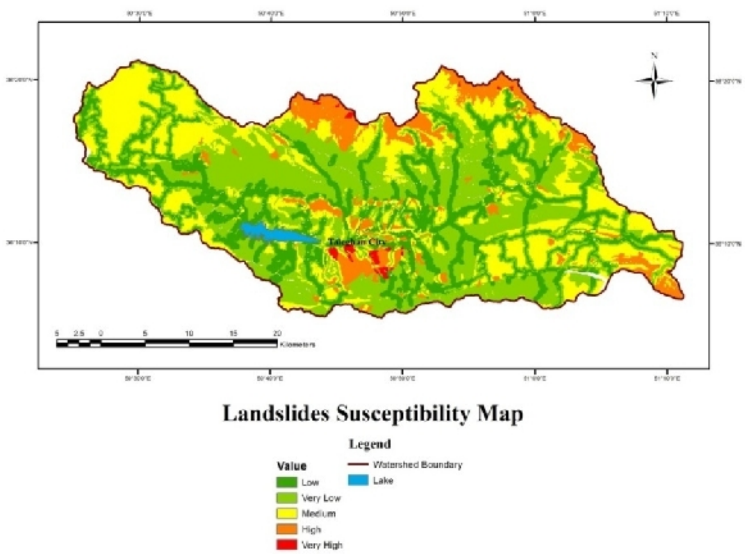


Fig. 6. Landslides susceptibility map of study area.

Landslide susceptibility map was reclassified into five susceptibility classes: very low, low, moderate, high and very high. According to this map 22.34, 30.75, 26.74, 15.61 and 4.56 percent of study area are located in very low, low, moderate, high and very high susceptibility classes, respectively.

Table 1: Distribution of landslides in susceptibility classes.

Susceptibility Class	Susceptibility area (%)	Observed landslide area (%)
Very low	22.34	10.43
Low	30.75	16.99
Medium	26.74	15.71
High	15.61	26.74
Very high	4.56	30.13

To validate the accuracy of the landslide susceptibility map, observed landslides and susceptibility map was compared. As it evident in Table 1 and Fig. 7, high percentage of the landslides has been occurred in very high susceptibility area that covers the lower percentage of study area. Despite of these results, multivariate regression model is suitable for susceptibility mapping in the study area.

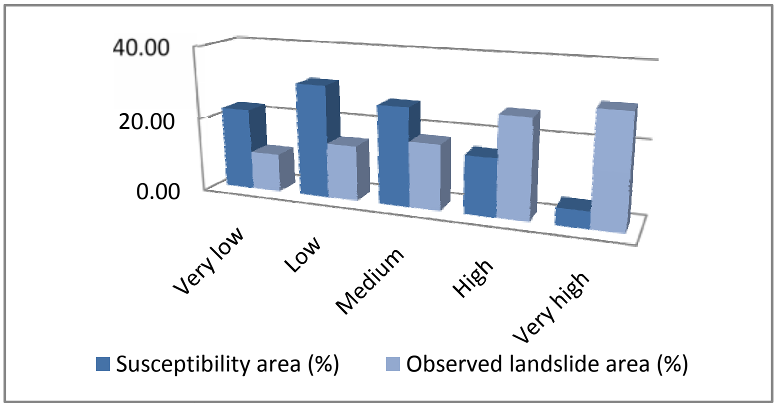


Fig. 7. Distribution of landslides area in susceptibility classes.

In Taleghan watershed, lithology had significant influences on landslide, according to Yalcin (2008). Lithology units including gy2 (grey mudstone and sandstone with low to medium salts and gypsum), gy1 (grey mudstone and sandstone with high salts and gypsum), Q2 (quaternary deposition), gy (gypsum), Jk (massive limestone) and Ekta (acid tuff) are very susceptible to landslide. Landslides have been occurred near to the rivers, according to Saha *et al*, (2002), Cevik & Topal, (2003) and Yalcin (2005). Observed landslides confirm that most of events are occurred near or close to the roads, as mentioned by Yalcin (2008) and Eshaghi (2009). According to Lee *et al.* (2004) and Yalcin (2008), the rate of landslide is increased with elevation. Poor rangeland and gardens are very susceptible to landslide, as experienced by Ayalew and Yamagishi (2005) and Yalcin (2008). Faults are important parameter in landslide. The effect of distance from faults has been the focus of study by Lee (2007). Most of observed landslides have been occurred on slope between 10% to 30%, which has been already proved, by Saha *et al.* (2002) Cevik and Topal (2003) and Yalcin (2008). In very steep slopes the soil depth and its load are decreased.

Considering aspect indicated that most of landslides are occurred in north and west directions, which is related to angle of sun radiation and rainfall, according to Saha *et al.* (2002) Yalcin, (2008), Eshaghi (2009). In addition, north aspect not exposed to radiation, therefore it is more wetly than other aspects.

CONCLUSION

The result shows that seven factors including lithology, distance from the river, distance from roads, elevation, land-use, distance from fault and slope angle, are more important than the others. With multivariate regression model interrelation existing between instability factors are more highlighted. As a final conclusion, the results from this study may be useful for land-use planning and decision making in landslide prone areas.

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