EFFICIENCY EVALUATION OF FOUR STATISTICAL LANDSLIDE HAZARD ZONATION METHODS USING GIS

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Abstract:

Prediction of spatial landslide occurrences and landslide hazard zonation is a suitable way to prevent more damages. Selection the best model to predict landslide occurrences help to decrease costs and time. Since different statistical and experimental landslide zonation methods were used by scientists. In this study, capability of four statistical methods including Valuing Information, Valuing Area Accumulation, Relative Effect and Landslide Numerical Risk Factor were investigated in the forested basin of Seyedkalateh watershed at the Ramian, northeast of Iran. An occurred landslides map of study area was generated by GPS and aerial photo interpretation. Topographic and geologic attributes together with land use, distance from fault, road and river were gathered from different creditable sources and maps. These attributes were imported in the GIS and were classified and weighted to main classes and scores. By importing these weighted attributes into mentioned models, the landslide hazard zonation was accomplished in the study area. Evaluation of obtained results of models were done using accumulation ratio in each hazard class and the Dr and Qs factors were calculated to evaluate result of models. Results shows that comparing to other used methods, the Relative Effect (RE) method had high Qs and consequently could better separate the hazard zones.

1. INTRODUCTION

The landslides are phenomenon which, almost occurs in slope of mountains. These movements have body and economic risks and increasing of soil erosion and sediment transportation into back of dams and cause serious damages in the world with numerous killed humans. Prediction of spatial landslide occurrences and landslide hazard zonation is a suitable way to prevent more damages. A landslide hazard zonation (LHZ) map depict the area of land surface into zones with varying degree of land stability, based on the estimated significance of causative factors. The LHZ maps are usually useful for different purposes. First, they help planners to choose suitable sites for sitting development schemes such as building and road constructions. Second, since the LHZ map delineates the areas into zones with varying degree of stability, the environmental regeneration measures can be initiated in high hazard areas by adopting suitable mitigation measures. Since, various approaches were attempted to develop quantitative models for predicting the landslide hazard (Mark and Ellen, 1995; Gorsevski et al. 2000). Since, the researcher have used two different based methods for landslide zonation including statistical models (Haghshenas, 1997; Van Westen et al., 1999; Fatahi Ardakani, 2000; Sefidgari, 2002; Chung et al., 2005; Shadfar et al., 2005) and experimental models (Hafezimoghadas, 1993; Fatahi Ardakani, 2000; Koorakinejad, 2001; Sefidgari, 2002; Dai et al., 2002; Habibi et al., 2005). These approaches are mostly based on either an infinite slope stability model using GIS (Okimura and Ichikawa, 1995) or statistical models, which are linked to environmental attributes based on spatial correlation (Carrara et al., 1995; Mark and Ellen, 1995; Chung and Fabbri, 1999). Since the early 1980s, the statistical models as the multivariate methods have been implemented using GIS (Carrara et al., 1992, 1995). Recently, researchers (Gorsevski et al., 2000) applied logistic regression for spatial prediction of landslide hazard. The researchers (Haghshenas, 1997; Van Westen et al., 1999; Guzzetti et al., 1999; Fatahi Ardakani, 2000; Chang and Slaymaker, 2002; Chung et al., 2005; Shadfar et al., 2005) concluded that statistical

models can accurately predict the landslide zones. Among statistical methods, the four applied methods including Landslide Numerical Risk Factor (LNRF) method (Shadfar et al., 2005), Relative Effect (RE) (Ghafoori et al., 2006 and Van Westen, 1999), Valuing Information (VI) (Shadfar et al. 2005; Sefidgari, 2002; Fatahi Ardakani, 2000; Haghshenas et al., 1997; Afjah, 2006) and Valuing Area Accumulation (VAA) (Afjah, 2006, Shadfar et al., 2005) are most used methods in landslide hazard zonation in the forested basins.
Regarding to high frequency occurrences of landslides in the northern forests of Iran, in the Golestan province, the main goal of this study is comparison of capability of four statistical models of VI, VAA, RE and LNRF in landslide hazard zonation in the forested basin of the Seyedkalateh watershed, northeast of Iran.

2. MATERIALS AND METHODS

2.1 STUDY AREA

The study area is located at the Seyedkalateh watershed, Ramian basin, Golestan province, in the north east of Iran. This study area includes about 3000 ha of Seyedkalateh watershed (Figure 1). Elevations are ranged from 310 to 2813 meter from sea level and slopes are varied among 0 and 45 degrees. Precipitation average is about 836 mm annually. Forest, agriculture lands, roads and some villages are the main land uses. In the last three decades, the some parts of forests in the study area were destroyed and changed to other land, used by rural people.

2.2 OCCURRED LANDSLIDE MAPPING

Occurred landslide data usually consist on a landslide inventory made in the field and land measurement by GPS or by aerial photo interpretation (Beguería, 2006). The occurred landslides in the study area have been inventoried using aerial photos interpretation and GPS field works and mapped in GIS (Figure 2).

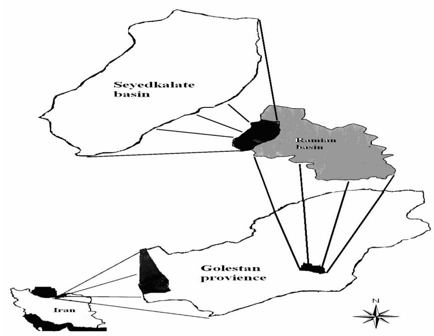

Figure 1: Location of the study area at the Seyedkalateh watershed in the Ramian basin, Golestan province, north east of Iran

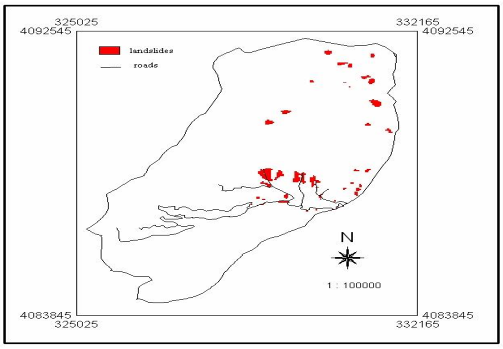

Figure 2: The occurred landslides map of study area inventoried by GPS and aerial photos interpretation

2.3 MAPPING OF EFFECTIVE FACTORS

The landslide hazard zonation methods needs to prepare and map the effective factors on landslide occurrence such as slope, land use, geology and distances from river, fault and road maps. Each of these factors was prepared from different methods and sources. A digital elevation model (DEM) was generated trough interpolating 10 meters contour lines of study area. The slope map was produced from DEM and classified to 0-20, 20-40, 40-60, 60-80 and 80-100 percent classes based on the turning points in the accumulative curve of slope map (Figure 3b). The geology map of the study area was generated by clipping the 1:100000 scale geology map of Ramian sheet produced by national geology organization of Iran (NGO). It is including seven geology units (Figure 3a). The faults were also extracted from geology map. The rivers, main and rural roads were extracted from topography maps and were then up to date trough GPS fielding work. The different distances from faults (3d), roads and rivers (3e) were made using buffer function. The land uses map of the study area was generated by classification of ETM+ imagery using maximum likelihood classifier into 6 classes including low density forest, density forest, semi density forest, range land, thinly rangeland and agriculture land uses (Figure 3c).

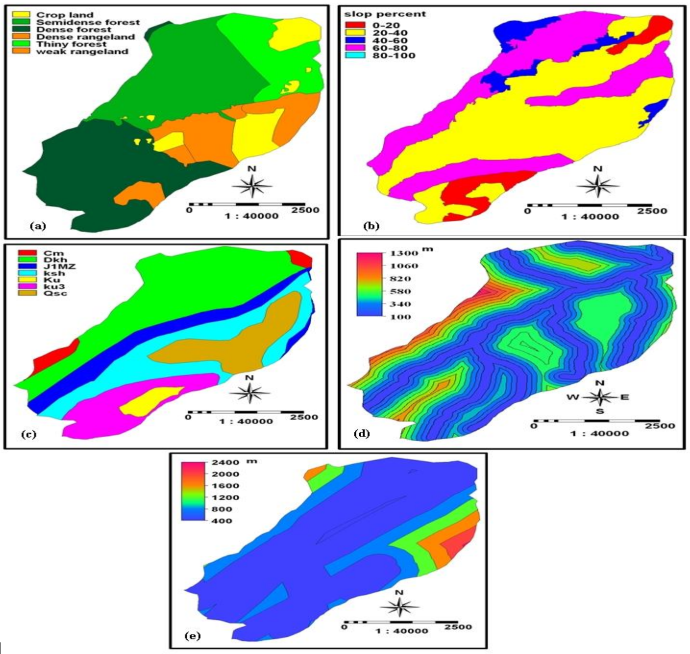

Figure 3: Effective factor maps, (a) Land use, (b) slope, (c) geology, (d) River buffer and (e) fault buffer

2.4 LHZ METHODS

2.4.1 RELATIVE EFFECT METHOD

In RE method, it is necessary to assess the relative effect of each parameter on the landslide occurrence, by calculating relative landslide density in each parameter. The relative effect of each class of parameters was also determined by dividing landslides area per each class to area of each class. To do this, inventoried landslide map was crossed to the slope, geology, land uses and distances from fault, river and road maps. The results of cross function are tables which are containing the rate of occurred landslides in the classes of each parameter. The relative values of each class (C) on occurred landslides, was calculated trough dividing the each class area (α) to total area (A) and were applied on the parameters, respectively.

$$C = \frac{a}{A} \times 100 \qquad \textbf{(1)}$$

And landslide percentage in the each unit (S) was calculated using dividing landslide area in each unit (*sld*) to total landslide area in study area:

$$S = \frac{sld}{SLD} \times 100 \qquad \textbf{(2)}$$

Consequently, the relative effect of each parameter (RE) was calculated based on logarithm of landslide percentage of each unit (S) to coverage percent of each parameter (C) plus epsilon to prevent of zero making:

$$R.E = Log\left[\left(\frac{S}{C}\right) + \delta\right] \qquad \textbf{(3)}$$

Then, the slid risk of study area was computed by sum relative effect of parameters on the unit area (formula 4). Since some classes have different impact on the landslide occurring, the weights (α) were considered for each parameter and classes to reduce redundant information.

$$sliderisk = \sum RE(REslope + REgeology + REdepth + REtexture + \ldots\ldots) * \alpha \qquad \textbf{(4)}$$

Finally, the landslide hazard map was created using accounting attribute of base map and sum of calculated weights. The landslide zonation map was classified based on classes (Table 1). These classes could determined by turning point on the accumulative carve of map.

Table 1: Ranking of hazard classes based on relative effect method

Slide risk	-4.9 to -3	-2.9 to 0.75	0.8 to 1.6
Hazard class	1	2	3

2.4.2 VALUING INFORMATION METHOD

In order to assessment the valuing information of each parameter on the landslide occurring, the cross function was used to cross the landslide map with the existing slope, geology, fault distance, river and road distance and land use maps. In order to calculate density values for active landslides, landslide density is calculated based on following formula:

$$W\inf = \ln\left[\frac{\frac{A}{B}}{\frac{C}{D}}\right] \qquad \textbf{(5)}$$

Where; A; landslide area of each classes (ha); B: class area (ha); C: total landslide area of watershed (ha); D: total area of watershed and Winf : Weight of valuing information method

And finally the slide risk is calculated based on following formula:

$$sliderisk = \sum W\inf \qquad \textbf{(6)}$$

Then, the hazard classes were ranked based on valuing information method (Table 2).

Table 2: Ranking of hazard classes based on valuing information method

Slide risk	-11 to -5.8	-5.7 to 1.3	1.4 to 5.9
Hazard class	1	2	3

2.4.3 VALUING AREA ACCUMULATION METHOD

In order to assessment the valuing area accumulation of each parameter on the landslide occurrence, density values of active landslides, was calculated based on the following formula:

$$Wa = 1000\left[\frac{A}{B}\right] - 1000\left[\frac{C}{D}\right] \qquad \textbf{(7)}$$

Where; A: landslide area of each classes (ha); B: class area (ha); C: total landslide area (ha); D: total study area (ha) and Wa : Weight of accumulated valuing area

And finally the slide risk rates would be computed from this formula:

$$sliderisk = \sum Wa \qquad \textbf{(8)}$$

Table 3: Ranking of hazard classes based on valuing area accumulation method

Slide risk	-95.778 to -60	-60 to -20	-20 to 223.8
Hazard class	1	2	3

2.4.4 LANDSLIDE NUMERICAL RISK FACTOR (LNRF) METHOD

The LNRF method is based on landslide area in each unit of agent maps and average of landslide area in total agent maps which was done by following formula:

$$LNRF = \frac{A}{B} \qquad \textbf{(9)}$$

Where, A: Landslide area in each unit and B: Average of landslide area in total agent maps
And finally the slide risk in each unit was calculated by following formula. The hazard class of slid risk map was ranked and classed based on Table 4.

$$sliderisk = \sum LNRF \qquad \textbf{(10)}$$

Table 4: Ranking of hazard classes based on LNRF method

Slide risk	0.3 to 0.6	0.7 to 2.1	2.2 to 3.1
Hazard class	1	2	3

2.5 EFFICIENCY EVALUATION OF METHODS

The generated landslide hazard maps were overlapped with occurred landslide map to calculate the percentage of landslide occurrence in each unit of landslide map. Finally, the applicability of the four landslide hazard zonation maps are investigated in the Seyedkalateh watershed using density relation (Dr) and quality sum (Qs) factors. The sum of quality values calculates with formula 11 and then the Qs rates have calculated using the formula 12 :

$$Dr = \frac{Si}{Ai} \Big/ \frac{\sum_{i}^{n} Si}{\sum_{i}^{n} Ai} \quad \textbf{(11)}$$

Where, Si: sum of landslide area of each risk class (ha); Ai: class$_i$ area of zonation map (ha); N: number of risk class and Dr is dense relation

$$Qs = \sum_{i=1}^{n} \left[(Dr-1)^2 \times S \right] \quad \textbf{(12)}$$

3. RESULTS AND DISCUSSION:

The landslide hazard map generated by different methods (Figure 4) showed that there are significant differences between hazards map that is made based on various models. The significance of results could be determined by computing of Density ratio (Dr) ratios (table 5) and the sum of quality (Qs) values showed in the table 6. There are different between areas of deferent landslides hazard zones. And these differences lead to produce deferent number of Qs and have effect on capability of landslide hazard zonation maps. The Dr Value shows the capability of each class in each model. The classes with high Dr value is better than other class.

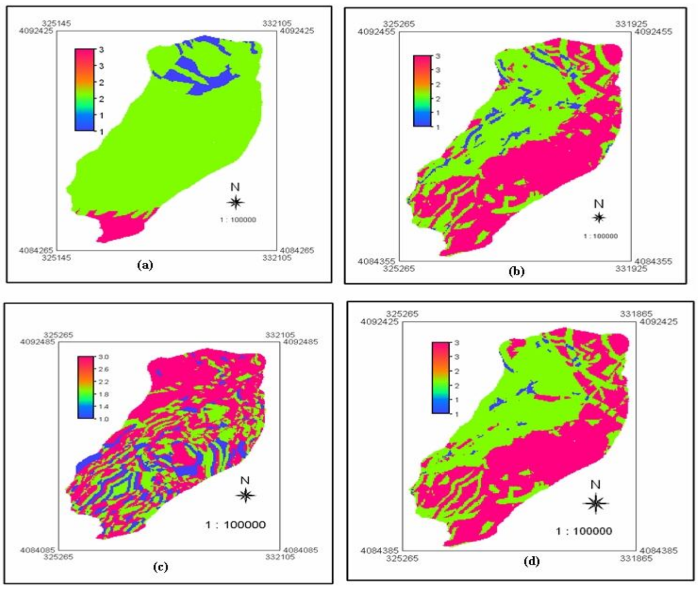

Figure 4: Landslide hazard zonation maps generated by different methods, (a) LNRF, (b) valuing information, (c) Valuing area accumulation and (d) Relative effect

Table 5- The Dr of each class in statistical models

Method\ Class	1 (low risk)	2 (moderate risk)	3 (high risk)
Valuing information	0	0.163068	1.84728
Landslide Numerical Risk Factor (LNRF)	1.217862	1.043166	0
Relative effect	0	0.135696	1.902234
Valuing area accumulation	1.329041	0.886117	0.975819

Table 6 – The Qs value of statistical model

Model	Relative effect	Valuing information	Landslide Numerical Risk Factor	Valuing area accumulation
QS	0.784241	0.721928	0.056835	0.019936

As it is showed in the table 6, the LNRF model does not seem suitable because of its low Qs and Relative Effect model is the suitable model for application in the Seyedkalate watershed because of its high Qs. This result is corresponded with result of Ghafori et al. (2006), which are described the relative effect method as a new and capable method in the all weather conditions without necessary expert knowledge to determine the weight of factors. Ven Westen et al. (1999) used a function for landslide zonation that is almost corresponded with relative effect function but, the benefit of relative effect method is ranking of effective factors in the landslide zonation. However, in this research, the four methods were analyzed but, using the other methods could be investigated to generate a landslide zonation map. Our analysis did not include some other attributes which have less impact on landslide occurring. A further refinement of the proposed model would include these low impact attributes.

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