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Performance Assessment of Two "LNRF" and "AHP-Area Density" Models in landslide Susceptibility Zonation

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ABSTRACT: The present research was aimed to evaluate landslide susceptibility in Chamran basin using tow quantitative models of LNRF and weighted semi-quantitative (AHP (Analytical Hierarchy Process) - area density). For this, using interpretation of aerial photographs and satellite Google Earth, GPS devices and reconnaissance, landslide distribution maps in scale 1:100000 were prepared in points manner, included 30 landslide cases of which, inspired from common methods, 30% (nine) were randomly selected and used to evaluate the performance of the models and the rest (21) were used for modelling. Seven key factors in the occurrence of landslide were selected including distance to river, distance to road, lithology, land use, slope, aspect and altitude. Information layers related to each parameter were prepared in GIS. Susceptibility value was calculated multiplying parameters value by parameter class value and landslide zoning map was prepared based on summing these values and pixels cumulative frequency turning points (Natural breaks). Models Performance was tested using indices summation of quality (Qs), the precision of predicted results (P) and relative performance characteristic (ROC). The results of indices showed that the weighted bivariate statistical model (AHP - area density) is more efficient for landslide distribution in Chamran area.
Key words: Analytical Hierarchy Process, Area Density, Mass Movement, Natural Breaks, Quantitative Models.

INTRODUCTION

There are many definitions about landslide presented in many papers and by many experts [1, 2]. Yet, the most common and the simplest definition expressed by Varnes [3]. As used here, the term 'Landslide' comprises almost all varieties of mass movements on slopes, including some, such as rock-falls, topples and debris flows, that involve little or no true sliding. Landslide phenomenon serves as one of the most important natural catastrophes as earthquake, flood, volcanic eruption etc. so its occurrence in area prone to which incurs remarkable damages and causalities. Today, the countries encountered to landslide issues tends to assess and zoning damages and develop a comprehensive integrated plan. As a whole, due to geographical conditions and lack of integrated comprehensive management and no environmental threshold measures, Iran is found to be one of top countries in landslide occurrence, so that of 43 natural catastrophe and anthropogenic ones, amount 38% are existed in Iran [4]. Landslide occurrence trend is directly related to population explosion specially those inhabited in landslide prone areas. On the other hand, landslide are much more predictable and manageable than other natural crisis like flood, earthquake etc. To zoning basin relative hazard, there have introduced dozens numerical models along with factors, weight, score, and calculation logic in difference scales under various conditions based on ground facts calibration. According to van Westen's sight [5], There is a general consensus that a classification of GIS-based landslide Susceptibility assessment methods may involve four different approaches: Heuristic approach, Multivariate statistical approach such as logistic regression model [6,7,8,9 and 10] or Bivariate such as LNRF model [11,12 and 13] and Information value model [13, 14] Probabilistic approach and Deterministic approach. He has also classified the landslide risk zonation methods to three categories including qualitative, semi-quantitative and quantitative. Anbalagan et al. [6], through seven key and mechanistic parameters of lithology, slope degree, slope faces, faults, land use, elevation, and hydrology at 1:50,000 scale and using scoring method based on landslide hazard assessment factor in the region Sukhidang India, regionalized the landslide hazard and subsequently after mapping losses and damages incurred on engineering infrastructures ,natural and anthropogenic resources according to risk assessment matrix as per (RAM), they merged both landslide hazard and damage map to obtain total landslide risk map. Dai et al. [11], have taken an overview in recent advances on the landslide, purposed a framework for landslide hazard and damages assessment and indicated In recent years, risk analysis and assessment has become an important tool in addressing uncertainty inherent in landslide hazards and recent advances in this case are beginning to provide systematic and rigorous processes to enhance slope management. Inspired from objective decisions and selection of four key parameters lithology, rainfall magnitude, earthquake intensity, vegetation and considering the parameters relation to

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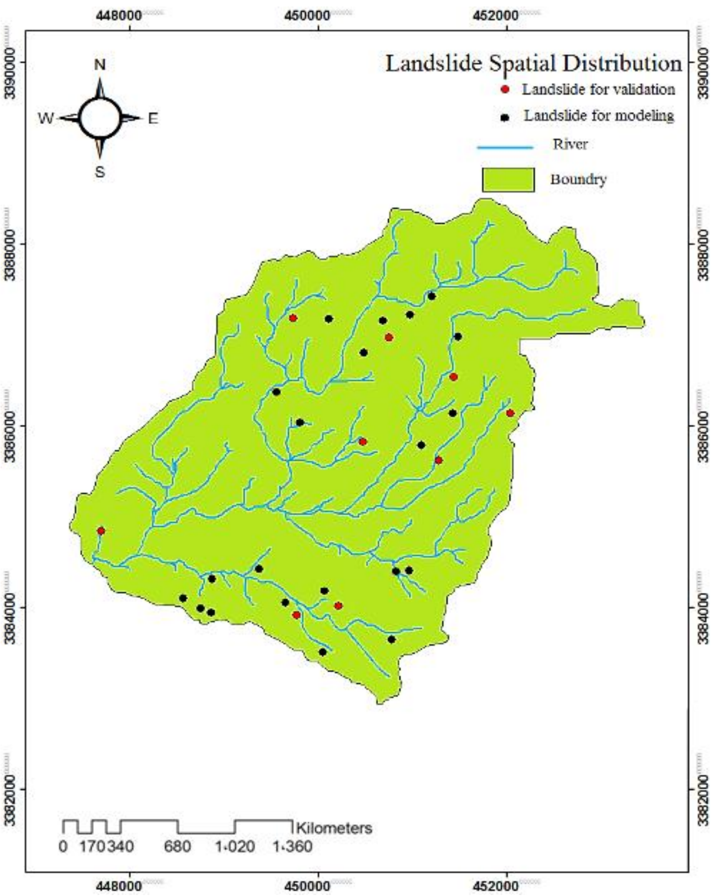
landslide in the basin, Mendoza et al. [13] prepared zonation map for landslide potential hazard in three classes (low, medium, high). Zêzere et al. [15], using quantitative (probabilistic) algorithm and establish a correlation between the time series in previous landslides and time series of rainfall in the north of Lisbon, Portugal, regionalized potential landslide hazard and mapped landslide risk according to general risk equation through three hazard maps, elements susceptibility and vulnerability elements to calculate direct cost like Remondo et al. [16] did in the Bajo Deba area (northern Spain). Kunlong et al. [17] attempted to build a local dynamic early warning system in Web-GIS on landslide through establishing a statistical relationship between the number and Statistics daily rainfall in Zhejiang China. This system is capable of sending alerts to users and also enable users to use the landslides information contained in this database as well. Finally landslide ecological risk was calculated by updating the information in this database (through daily rainfall forecast map obtained from Meteorology institution) and specifying distribution of susceptible elements using the general risk equation. Martha et al. [18] have noted that in recent literatures have been carried out to prepare landslide inventories from satellite data by automatic methods, however, almost no attempt has been made to validate the effect of such inventories on landslide hazard and risk assessment. Finally they have shown how landslide inventories prepared by semi-automatic methods from post-event satellite images can be used in the assessment of landslide susceptibility, hazard and risk in the High Himalayan terrain in India. Most spatial models of the hazard lack reliability tests of the procedures and predictions for estimating the probabilities of future landslides, thus precluding use of the maps for probabilistic risk analysis. To correct this deficiency Chung and Fabbri [10] propose a systematic procedure comprising two analytical steps: “relative-hazard mapping” for overall prediction and “empirical probability estimation” in each prediction class by applying a cross-validation technique that called a "Blind test". Listo and Viera [19] analyze the probability of risk and susceptibility to shallow landslides by cadastral survey and SHALSTAB (Shallow Landsliding Stability) mathematical model respectively in the Limoeiro River basin of São Paulo and finally have found that This combination of methods can be applied to evaluate the risk of shallow landslides in densely populated areas and can assist public managers in defining areas that are unstable and inappropriate for occupation. The recent practices in chase of landslides are impressive such as ability to predict the approximate time of failure [20] and emersion of dynamic comprehensive methods for landslide control which take full advantage of updated monitoring data and site investigations of landslides, and emphasize the implementation of possible measures for landslide control at reasonable stages and in different groups [21]. Also Climate change has become part of the general awareness and started to be taken into account in the municipal spatial planning to reduce the landslide risk [7].

MATERIAL AND METHODS

Study area

Chamran watershed coordinates is 30 37 41 to 30 34 7 N and 50 30 52 and 50 27 5 E, in 1785 h area over 30 km distance from Behbahan city in Khuzistan province (Fig. 1). Landslide types in study area were classified in five classes of falling, rotational, transitional, and complex and creep according to the Varnes classification.

Figure 1. Landslide spatial distribution in the Chamran basin



Mapping landslide distribution, selection and classification of effective factors

One of the most important steps of landslide susceptibility assessment, is to identify and map landslide distribution in the basin. For this purpose the software Google Earth, reconnaissance, information and local guides, device GPS were uses and landslides map was prepared in point manner within in the Chamran basin. To select optimal parameters (Fig. 2), principle component analysis (PCA) in the software Idrisi and objective approaches were used (Table 1). The main idea behind this method is to establish a correlation between the maps, so that maps have high correlation with each other, causes bias in the final zoning result and one of which should be eliminated through objective approaches.

Landslide Hazard zonation using model LNRF

This model was first developed by Gupta and Joshi [22] based on parameters classes scoring as per following formula:

Equation 1. $LNRF = \frac{Si}{\bar{S}}$

Where,

Si is number of landslide per class and is the average number of landslides in total class of each parameter.

In other words, the computational logic of scoring in model LNRF, is dividing. According to this approach parameters are not weighted themselves. In this study, after scoring classes of seven variables effecting landslides, mapping parameters was conducted in GIS and hazard map were classified in five range (very low , low moderate, high and very high) based on the cumulative frequency of the curve turning points of pixels.

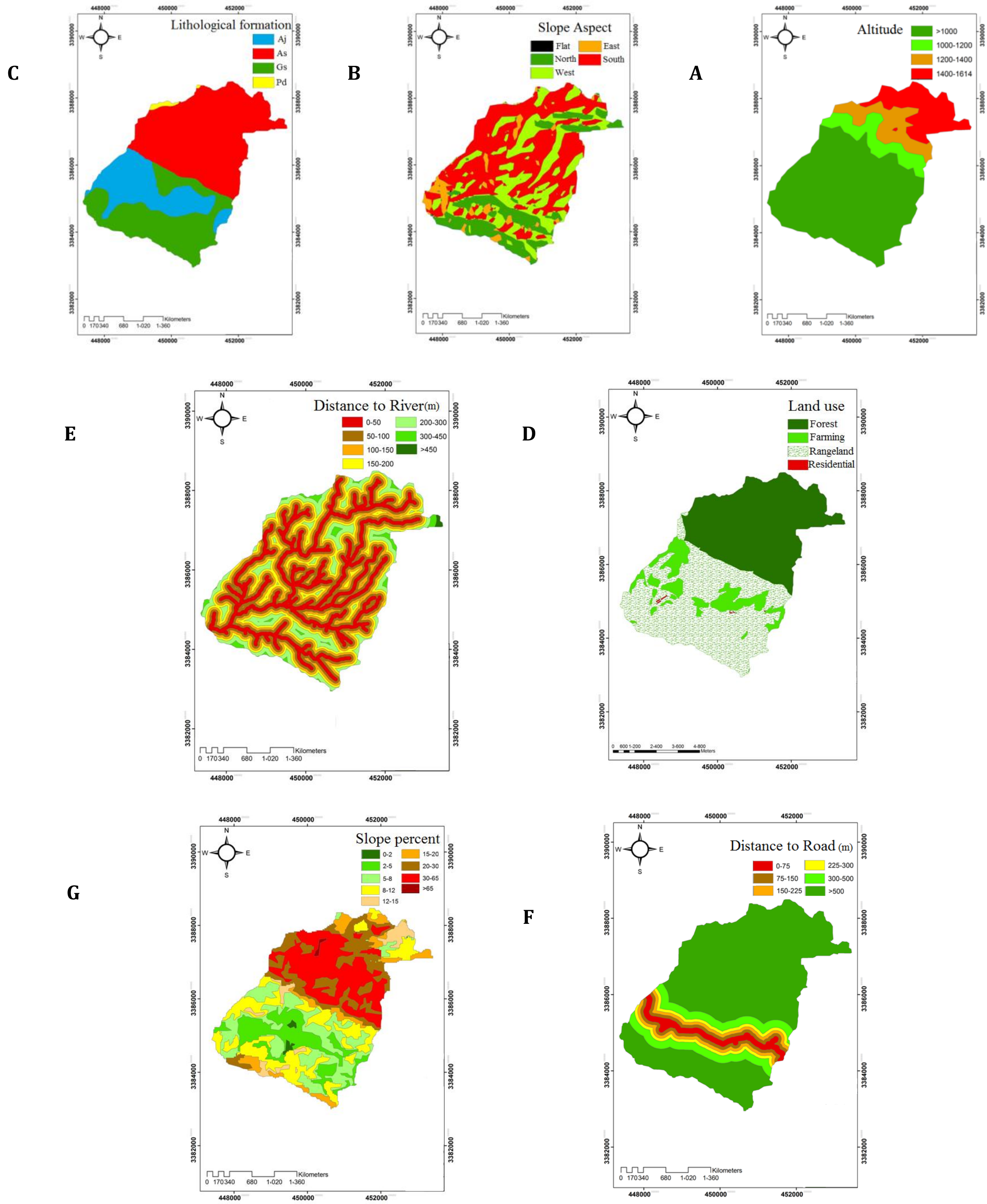


Figure 2. Key parameters affecting landslide in the Chamran basin; a slope aspect, b altitude, c lithological formation, d land use, e distance to river, f distance to road, g slope percent

Landslide hazard zonation using weighted bivariate statistic model (AHP-area density)

To scoring parameter classes, this model uses bivariate statistical methods of area density and to weight parameters themselves applies Analytical Hierarchy Process [23]. As a result, as it is illustrated on title, indicates whole process be modeled According to this method. To weighting determinant parameter in landslide, a questionnaire containing table of paired comparisons in parameters and classes were presented to 5 professors and 5 executive director as well as 5 experts. In these comparisons, the decision makers use oral judgment. Such judgments has become slightly between zeros to nine by Saaty [24].

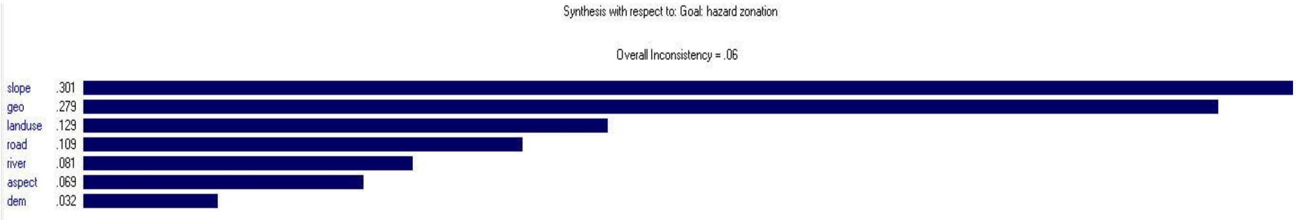


Figure 3. Expert choice 11 outputs indicating final weights of parameters

Table 1. Correlation matrix between parameters (PCA)

PCA Matrix	Slope Aspect	Distance to Road	lithology	Land use	Distance to river	Elevation	Slope
Slope Aspect	1	0.46	0.7	0.55	0.63	0.4	0.43
Distance to Road		1	0.71	0.67	0.55	0.55	0.81
lithology			1	0.51	0.47	0.69	0.47
Land use				1	0.35	0.44	0.55
Distance to river					1	0.67	0.67
Elevation						1	0.6
Slope							1

Finally, nine reasonable questionnaires were selected and the geometric mean responses was entered to software Expert choice 11 in matrix manner. To score parameter classes, area density method was used as follow:

Equation 2. $Warea = 1000\,(\frac{A}{B} - \frac{C}{D})$

Where,

Warea is area density index, A is number of landslide per class, B each class area, C total number of landslides and finally, D total area of basin. The best equation for effective factors and landslide absence and presence as well as landslide susceptibility map was produced in software Arc GIS, then classified based on turning points of cumulative frequency curves of pixels in five classes of susceptibility (very low to very high).

Performance assessment of model to zonation of landslide susceptibility

Density ratio index is used to compare hazard classes in individual maps independently (Eq. 3).

Equation 3. $Dr = \frac{\frac{Si}{Ai}}{\frac{\sum_1^n Si}{\sum_1^n Ai}}$

Where,

Dr: landslide density in each hazard class, Si: total number of landslides in each hazard class, Ai: area for each hazard class in zonation map and n: is number of hazard class.

The better hazard class distinguished, the more desirable map. Quality summation indicates model performance in predicting landslide hazard in area.

This index ranges 0-7 for different models, although it is infinite theoretically. While model validation, the more quality summation index value, and the more model ability to distinguish. Quality summation index value is obtained from equation 4:

Equation 4. $Qs = \sum_{i=1}^{n}((Dr-1)^2 \times S)$

Where,

Qs: is quality summation, Dr: density ratio, S: area ratio in each hazard class to total area and n: is number of hazard class.

To compare zonation maps, Precision of the Predicted results was considered. This index is calculated from equation 5.

Equation 5. $P = \frac{Ks}{S}$

Where,

P: Precision of the Predicted results, Ks: landslide area in hazard class (moderate to very high) and S: total landslide areas in region.

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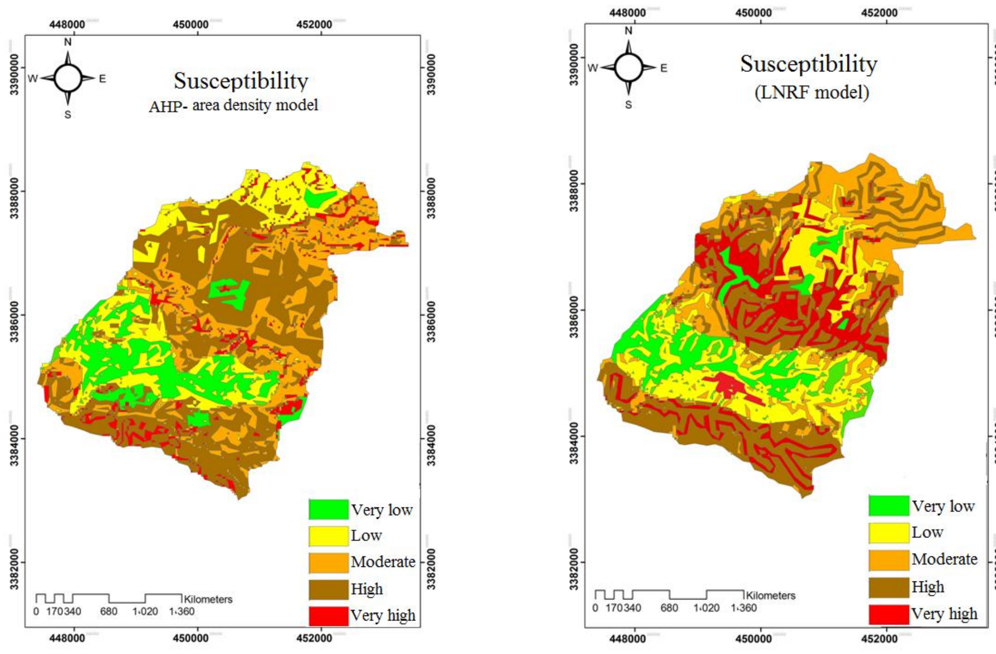
Table 2. Scoring parameter classes by LNRF and Area Density models

Parameter	Class	S	$\bar{S}$	LNRF	Area density	Parameter	Class	S	$\bar{S}$	LNRF	Area density
Altitude	<1000	13	5.25	2.47	1.06	Land use	Forest	8	5.25	1.52	-1.47
	1000-1200	3		0.57	-2.74		Farming	0		0	-11.94
	1200-1400	5		0.95	15.55		Rangeland	13		2.47	4.2
	1400-1614	0		0	-11.94		Residential	0		0	-11.94
Slope percent	0-2	0	2.33	0	-11.94	Lithology	Aj*	0	5.25	0	-11.94
	2-5	2		0.85	-2.77		As*	10		1.9	-0.52
	5-8	3		1.28	-2.37		Gs*	11		2.09	10.15
	8-12	3		1.28	-2.5		Pd*	0		0	-11.94
	12-15	3		1.28	32.3	Slope aspect	Flat	0	4.2	0	-11.94
	15-20	2		0.85	5.67		North	8		1.9	15.76
	20-30	2		0.85	-4.38		West	8		1.9	4.56
	30-65	6		2.57	4		East	1		0.23	-1.76
	> 65	0		0	-11.94		South	4		0.95	-7.02
Distance to road	0-75	0	3.5	0	-11.94	Distance to river	0-50	2	3	0.66	-7.81
	75-150	0		0	-11.94		50-100	11		3.66	13.54
	150-225	0		0	-11.94		100-150	3		1	-3.36
	225-300	1		0.28	2.26		150-200	1		0.33	-7.94
	300-500	1		0.28	-6.27		200-300	4		1.33	7.54
	>500	19		5.42	2.87		300-450	0		0	-11.94
							> 450	0		0	-11.94

Description: Aj (Aghajari formation, Cenozoic (Miocene), consist of gypsum, red marl and siltstone), As (Asmari formation, Cenozoic (Oligocene), consist of limestone and dolomite), Gs (Gachsaran formation, Cenozoic (Miocene), consist of anhydride, halite, Marl and lime) and Pd (Pabdeh formation, Mesozoic (Cretaseous), consist of lime and shale).

Table 3. Expert choice 11 outputs indicating final weights of parameters

Parameter	Final weight
Slope percent	0.301
Lithology	0.279
Land use	0.129
Distance to road	0.109
Distance to river	0.081
Slope aspect	0.069
Altitude	0.032



A B

Figure 4. Landslide susceptibility zonation using a: AHP- area density model and b: LNRF model

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ROC is a given model relative operating characteristic. It can be calculated from ROC curve. The ROC curve is a plot in which pixel ratio representing occurrence or non-occurrence of the landslide prediction accurately (true positives) against the complementary value i.e. pixel ratio predicted inaccurately (false positive) is plotted. This index was calculated in the software Idris between landslide susceptibility and landslides presence-absence map.

RESULTS

As a whole, number of thirty landslides were recorded in study area whose map was prepared in ArcGIS. Determinant parameters in landslide were determined using PCA test and their map was prepared in the ArcGIS environment. The greatest and lowest correlations were observed between the parameters of distance to road and the slope percent as high as 81 percent, and the distance to river and land use as much as 35 percent respectively. Thus, taking trigger role of the both parameter (distance to road and the slope percent) in landslide, seven parameters of distance to river, distance to road, lithology, land use, slope, aspect and altitude are allowed.

Table 4. Comparison of two landslide susceptibility zonation methods using three indices

Index / Model	Class	Si	Ai	S	$\frac{\sum_i^n S_i}{\sum_i^n A_i}$	Dr	$(Dr-1)^2 \times S$	Qs (%)	P (%)	ROC (%)
LNRF	Very low	0	302.12	0.172	0.012	0	0.17	72.8	95.23	85
	Low	1	271.73	0.155		0.3	0.07			
	Moderate	1	312.32	0.178		0.26	0.09			
	high	11	576.33	0.328		1.59	0.11			
	Very high	8	295.42	0.168		2.26	0.27			
AHP	Very low	0	200.91	0.114		0	0.11	85.5	100	82
	Low	0	190.76	0.109		0	0.1			
	Moderate	2	572.32	0.326		0.29	0.16			
	high	16	640.46	0.364		2.09	0.43			
	Very high	3	153.12	0.087		1.64	0.03			

Landslide susceptibility map preparation by different models

According to table 2 and computation algorithm of models, class parameters were scored. In AHP after entering the final matrix parameters and paired comparisons as well as their levels to the Software Expert choice 11, parameters class values were calculated using eigenvector method as a current most accurate method (table 3, figure 3). As it can be seen, inconsistency equals to 0.06 or less than 0.1 is in acceptable range. Landslide susceptibility map for two models are shown in figure 4.

Comparison of different landslide susceptibility zonation methods

Overlaying different landslide susceptibility maps to landslide evidence maps, indices of Qs and P were calculated (table 4).

Table 5. Ranking of landslide susceptibility models using corresponding indices

Rank	**Qs (%)**		**P (%)**		**ROC (%)**		**Final Rank**
	Model	**Value**	**Model**	**Value**	**Model**	**Value**	**Model**
1	AHP- ad*	85	AHP-ad	100	LNRF	85	AHP-ad
2	LNRF	72	LNRF	95.23	AHP-ad	82	LNRF

Description: (*AHP-area density model)

DISCUSSION AND CONCLUSION

Here, performance and efficiency of two models of LNRF and weighted bivariate statistical model were used to zoning landslide hazard using four methods of Qs, P, ROC and Chi square in the Chamran basin. After ranking different models, respectively in (Table 5), AHP Weighted bivariate statistical model was chosen as the top model. As seen in Table 6 Weighted bivariate statistical model is superior. Statistical bivariate model due to considering different parameters involved in the landslide separately, are less preferred over multivariate statistical models. These results are in line with Anbalagan et al. [6], Varnes [3], Komac [22] and Fanyu lio [14] and in contrast with Mohammadi et al. [25] and Naderi et al. [26]. Hence, integration of a bivariate statistical model –just able to score parameters classes- with a semi-quantitative model (AHP) allows to even weight parameters and provides a more acceptable result compared to a mere bivariate statistical model (LNRF) as observed in this research. Exerting parameters weight in classes score, it was found that slope (9.72) in class 12-15%, lithology (2.83) in Gachsaran formation, distance to river (1.09) in class 50-100 m, slope aspect (1.08) in north class, land use (0.54) in rangeland class, altitude (0.49) in class 1200-1400 m and distance to road (0.31) in class up to 500 m were introduced as determinant factors in landslide occurrence respectively. In other words, three principle parameters in landslides (slope percent, lithology and distance to river) are natural factors, so area landslide intrinsic potential should be taken into account. However, one or more factors may not be considered as principle ones, rather a set of anthropogenic and natural factors are iterating to cause landslide. It is worthy to debate that in the present research, lack of map scale similarity due to some map deficiency like lithology, topography and essentiality of downscaling maps to limiting factors (landslide scale), as a tolerable error range should be accepted (in terms of up-scaling some polygon maps like lithology with no additions). Finally it is recommended to use determinant parameters like soil depth and properties, distance to fault and rainfall (amount and intensity) along with this research parameters (in different parameters classification) as well as different landslide zonation models and their results be compared to those from the present study.

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