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Investigation of Pedological Criterion Affecting on Desertification in Alluvial Fans Using AHP-TOPSIS Technique (Case Study: South East of Roudeh-shoor Watershed)

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Abstract

Investigation of desertification trend requires an understanding of phenomena that create changes singly or action and reaction together in an area that these changes were led to the desertification and land degradation. In the investigation of pedological criterion affecting on land degradation in Alluvial Fans, first, the map of units was created by overlaying and crossing maps of slope classes, land use, geology and grid layer created by extension of ET Geo-Wizards in ArcGIS 10.3. In this research, three indices of erodibility, salinity and permeability of soil were considered and classified. Then, the weights of each criteria and consistency ratio were calculated by the AHP method. The TOPSIS method was used to prioritize the alternatives in this research. After calculating the weighted normalized values, Euclidean distances and the relative closeness to the ideal solution were calculated. The results show that the relative closeness to the ideal solution obtained from AHP-TOPSIS technique alters from 0.016 to 1.000. The alluvial fans in the research area were classified into three classes of I, II, and IV from the view point of pedological criterion affecting on desertification using AHP-TOPSIS technique. The obtained results showed that 74.18 % of the area is in the low desertification potential, and 3.37 % and 22.45 % are in the high and very high desertification potential, respectively.

***Keywords*:** Erodibility; Salinity; Permeability; Priority; MCDM

1. Introduction

Since Lampery reported the south advancement of the Sahara Desert at an average rate of 5-6 km/year in the period 1958-1975 in the UNESCO/UNEP conference in 1975, "desert encroachment" or "desert advancing" or "desert marching" in Africa had drawn the attention of a great number of institutions, individual scientists and governments and "desertification" has become one of the major subjects of dryland environmental research in the world in the past decades (Wu *et al*., 2008). The land degradation occurs everywhere but is defined as desertification when it occurs in the drylands, resulting from various factors, including climatic variations and human activities (UNCCD, 2012).

Vegetation is an effective way to prevent soil erosion and plays an important role in soil and water conservation (Lieskovský and Kenderessy, 2014). The vegetation on the slopes increases hydraulic roughness and vegetation, and creates the most resistance compared to the other surface roughnesses (Zhao *et al*., 2015).

Feiznia (1997 and 2008), Kashki (1997), Rajabi Aleni (2001), Sarabian (2002), Esenov *et al*., (1999), and Metternicht *et al*. (1996), Karimpour Reihan *et al*. (2013), Xu *et al*. (2015), Vieira *et al*. (2015), Sadeghiravesh *et al*. (2014),

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and Eskandari *et al*. (2016) investigated the desertification and land degradation from different aspects. Tahmasebi (1998) investigated the factors affecting on water and soil salinization and the spread of desert in the Roudeh-shoor area of Eshtehard and distinguished point pollution sources (salt domes) and diffuse (evaporate marl) and their effects on water and soil degradation. Vieira *et al*. (2015) Identified areas that are susceptible to desertification in the Brazilian northeast. The objective of their study was to identify the areas that are susceptible to desertification in this region based on the 11 influencing factors of desertification (pedology, geology, geomorphology, topography data, land use and land cover change, aridity index, livestock density, rural population density, fire hot spot density, human development index, conservation units) which were simulated for two different periods: 2000 and 2010. The results indicated that 94% of the Brazilian northeast region is under moderate to high susceptibility to desertification. Feiznia (1995) investigated erodibility of kinds of rock units in different climate and has exhibited resistance coefficient to erosion. Salehpour Jam (2006) investigated desertification potential of kinds of rock units in Roudeh-shoor watershed using the fuzzy logic method. He introduced function of 0.8 from the fuzzy logic model (gamma = 0.8). Van Lynden *et al*. (2004) suggested that soil quality is the most restrictive land change concept, followed by land quality and then sustainable land management. Symeonakis *et al*. (2014) estimated the environmental sensitivity areas on the island of Lesvos (Greece) through a modified ESAI, which included 10 additional parameters related to soil erosion, groundwater quality, demographic and grazing pressure, for two dates (1990 and 2000). This study identified areas that are critically sensitive to the eastern side of the island mainly due to human-related factors that were not previously identified.

The AHP is a very flexible and powerful tool because the scores, and therefore the final ranking, are obtained on the basis of the pairwise relative evaluations of both the criteria and the options provided by the user. The technique for order preference by similarity to ideal solution (TOPSIS) method proposed by Hwang and Yoon is an easy and useful method to help a decision maker select his/her best choice according to both the minimal distance from the positive-ideal solution and the maximal distance from the negative-ideal solution. Shih *et al*. (2007) listed four kinds of advantages of the TOPSIS method, such like a sound logic that represents the rational of human choice; a scalar value that accounts for both the best and worst alternative simultaneously; a simple computational process that can be easily programmed into a spreadsheet; and the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions. MCDM techniques were used to determine desertification potential by several researchers. For instance, Grau *et al*. (2010) and Sadeghiravesh *et al*. (2014). Grau *et al*. (2010) used the three models of ELECTRE, AHP and PROMETHEE to find the optimal alternatives in order to provide an integrated plan to control erosion and desertification. The obtained results indicate the high performance of these models for presenting optimal de-desertification alternatives. In addition, Sadeghiravesh *et al*., (2011) used the AHP model to prioritize alternatives to combat desertification based on EC software. Sadeghiravesh *et al*. (2014) assessed de-desertification alternatives using AHP-ELECTRE in the Khezr Abad region, Yazd province. The results indicated that prevention of unsuitable land use changes, vegetation cover development and reclamation, and changes in groundwater harvesting, with weight averages of 22.9, 21.8 and 19.1 %, respectively, are the most important desertification alternatives in the study area.

Investigation of desertification potential in Alluvial Fans located in the South East of Roudeh-Shoor watershed that consist of fans originated from different susceptible geological formations to erosion, such as marls using multiple criteria Decision making and attributes affecting on desertification is very crucial. The aim of this research is presenting indices to determine the role of pedological criterion affecting on desertification and prioritization of desertification potential in research area using AHP-TOPSIS technique.

2. Materials and Methods

2.1. Study area

Roudeh-shoor watershed area is about 17000 square kilometers. 42 and 58 percent of the area are plain and highland, respectively. This area has been located in the geographic extent of 48º 30′ to 51º (East) and 35º 21′ to 36º 30′ (North) and between two different geological systems and structures of south Alborz and central Iran. In this research, the alluvial fans located in the south east of this watershed were investigated from the viewpoint of pedological criterion affecting on desertification using AHP-TOPSIS technique (Fig. 1).

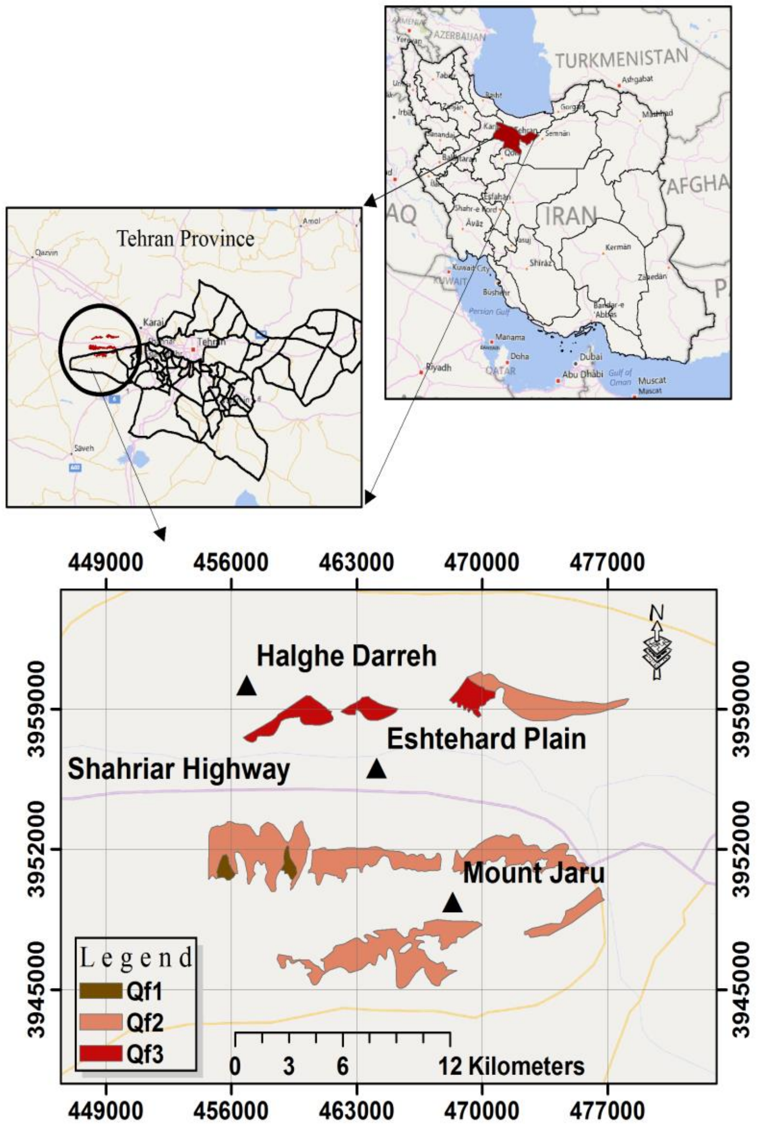

Fig. 1. Research area in south east of Roudeh-shoor watershed, Tehran province, Iran

2.2. Methodology

2.2.1. Soil sampling and analysis

To investigate pedological criterion affecting on land degradation and desertification in alluvial fans, first, a part of the Roudeh-shoor watershed was selected. After distinguishing target area, maps of slop classes, land use and geology were created, and then a map of units was created by overlaying and crossing them.

To create geological map, first, sheets of Eshtehard and Karaj were mosaiced and georeferenced using ArcGIS 10.3. According to the different names of rock units on Eshtehrd and Karaj sheets, denomination of rock units to be done on the basis of Karaj sheet (Fig. 2). The lithological characteristics of alluvial fans are presented in Table 1.

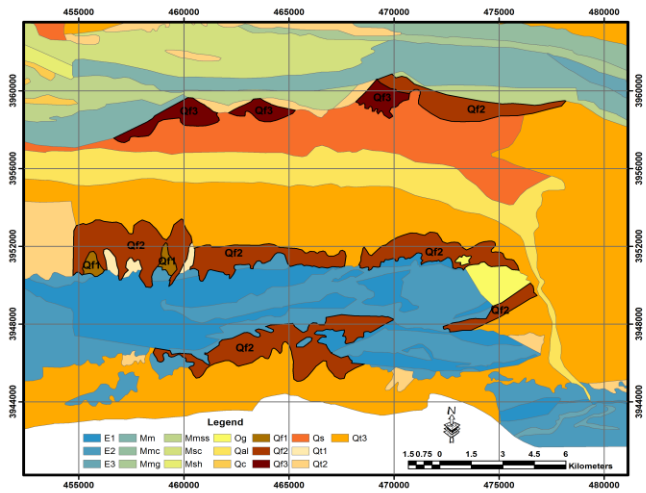

Fig. 2. Geological map of the study area, south east of Roudeh-shoor watershed, Tehran province, Iran

Table 1. Alluvial fan characteristics of the research area

Area (ha)	Lithological characteristics of search area	Sig.	Age		
			epoch	period	era
798.7	Youngest gravel fans	Q_3^f	-		
4773.1	Young gravel fans	Q_2^f	-	Quaternary	Cenozoic
152.2	Old gravel fans	Q_1^f	-		

To create map of slope classes, first, digital elevation model (DEM) was created using ArcGIS 10.3 software, then slop map was created. It was shown as the classified map using slope classes of 0-1 (class 1), 1-2 (class 2), 2-4 (class 3), 4-8 (class 4), 8-15 (class 5), and >15 (class 6) illustrated in Figure 4. Land use map of "Watershed Atlas" (SCWMRI, 2008) was used after monitoring and investigating the target area using Google Earth, Landsat 8, and field studies (Fig. 3).

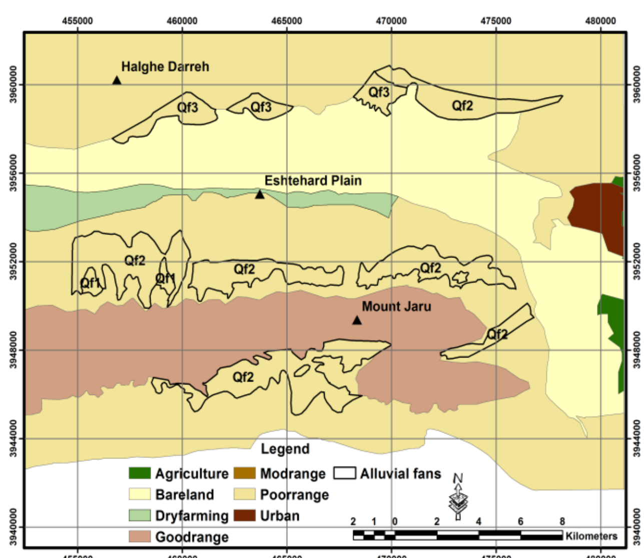

Fig. 3. Map of land use of research area, south east of Roudeh-shoor watershed, Tehran province, Iran

After creating three maps of rock unit, slope classes and land use, map of work units was created using ArcGIS by overlaying and crossing them. After creating units, grids of 1000*1000 square meters in the target area were created using an extension of ET GeoWizards in ArcGIS software to create more units.

In this step, the research area from the viewpoint of resistance coefficient to erosion was classified into two classes on the basis of the soil texture samples and coefficient of erodibility derived from Morgan table (1986) and also the limits of resistance coefficient to erosion derived from the Feiznia method (1995).

Then, Research area zonation from the viewpoint of the salinity index to be done. For this reason, first, sampling to be done and electrical conductivity of saturated mud of 159 samples were measured by EC-meter by mmhous.cm-1 and finally classification of salinity with considering 4 classes of salinity (low ($0 \le ECe < 2$), moderate ($2 \le ECe < 4$), high ($4 \le ECe < 8$) and very high ($8 \le ECe$)) to be done according to USSL method (1954).

In this step, Research area zonation from the viewpoint of the permeability coefficient to be done. To classify the area from viewpoint of permeability coefficient, sampling of 174 samples by brazen rings to be done and permeability coefficient of them was measured according to Darcy′ s law by meters per day (m.day-1), and finally classification of permeability based on 4 classes of permeability coefficient of very low (<0.069 cm.min -1), low (0.069-1.388 cm.min -1), moderate (1.388-6.944 cm.min -1) and high (> 6.944 cm.min -1) to be done according to Bouwer classification (1978).

2.2.2. Computing weights and prioritization

In order to compute the weights for the different criteria, the following steps to be done using the AHP method:

(1) Creating a pairwise comparison matrix. The comparisons between each criterion were made using the measurement scale of Satty, which give numerical values between 1 and 9 depending on the relative importance of the criterion. In this research, three indices of resistance to erosion, salinity and permeability of soil were considered and the AHP questionnaires were filled by 24 experts.

(2) Creating the normalized pairwise comparison matrix

(3) Calculating the weights of criteria

(4) Calculating the Consistency Ratio (CR) (Equation 1).

$$CR = \frac{CI}{RI} \qquad (1)$$

That: RI is a Random Inconsistency Index that is obtained from Table 2. CI is Consistency Index. It is calculated by Equation 2:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (2)$$

That: N is the number of options in the decision matrix (order of the matrix), and λmax is the maximum eigenvalue and calculated by averaging the value of the consistency vector.

Table 2. Random inconsistency indices (Satty, 1980)

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1. 46	1. 49

In this research, TOPSIS method was used to prioritize the alternatives. A positive ideal solution maximizes the benefit criteria or attributes and minimizes the cost criteria or attributes, whereas a negative ideal solution maximizes the cost criteria or attributes and minimizes the benefit criteria or attributes. The basic principle of the TOPSIS method is that the best alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. In this research the following steps to be done to set priorities using TOPSIS method (Hwang and Yoon, 1981):

(1) Calculating the normalized value n_{ij} .

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \qquad (3)$$

for $i \in I = \{1,2,\cdots,m\}$ and $j \in J = \{1,2,\cdots,n\}$.

(2) Calculating the weighted normalized value v_{ij} .

$$v_{ij} = w_j n_{ij}, \ \forall i \in I, \forall j \in J. \qquad (4)$$

Where w_j is the weight value of the j^{th} criterion, and

$$\sum_{j=1}^{n} w_j = 1 . \quad (5)$$

Determining the positive-ideal solution (A^+) and the negative-ideal solution (A^-).

$$A^+ = \{(v_1^+, v_2^+, \cdots, v_n^+)\} = \{(\max_i v_{ij} | j \in S_B), (\min_i v_{ij} | j \in S_C)\} \quad (6)$$

$$A^- = \{(v_1^-, v_2^-, \cdots, v_n^-)\} = \{(\min_i v_{ij} | j \in S_B), (\max_i v_{ij} | j \in S_C)\} \quad (7)$$

Where S_B and S_C denote the set of benefit criteria and set of cost criteria, respectively.

(3) Calculating Euclidean distance and the relative closeness to the ideal solution

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \forall i \in I. \quad (8)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \forall i \in I. \quad (9)$$

$$R_i = \frac{d_i^-}{d_i^+ + d_i^-}, \text{For } i \in I. \quad (10)$$

(4) Ranking the preference order.

For ranking alternatives by this index, the best alternative was chosen with the maximum value of relative closeness.

3. Results

The maps of slope classes and work units of research area have been illustrated in Figures 4 and 5.

The obtained results from zoning research area from the viewpoints of indices of resistance to erosion, salinity and coefficient of permeability have been illustrated in Figures 6 to 8, respectively.

Mean Values of Criteria in Each Unit were presented in Table 3.

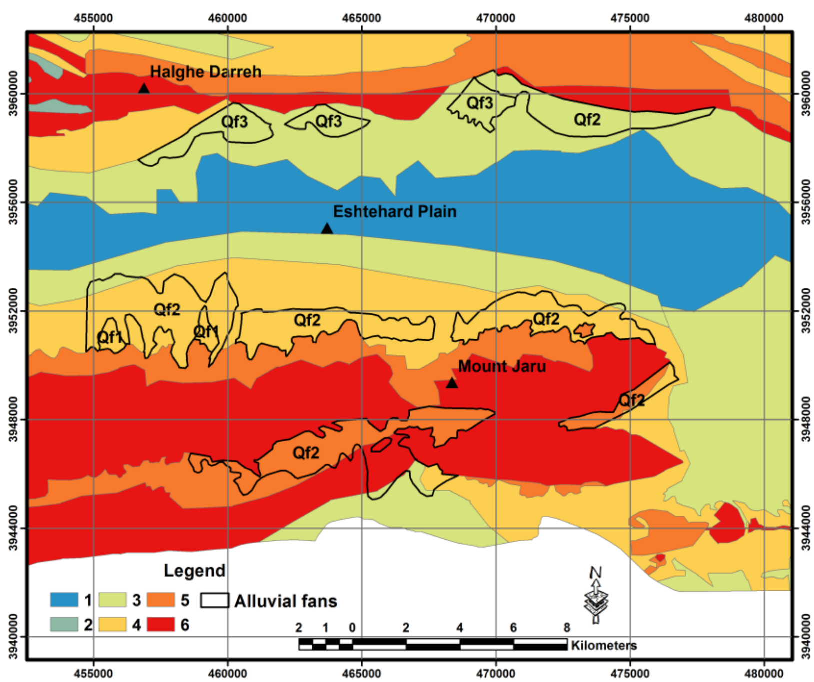

Fig. 4. Map of slope classes, South East of Roudeh-shoor watershed, Tehran province, Iran

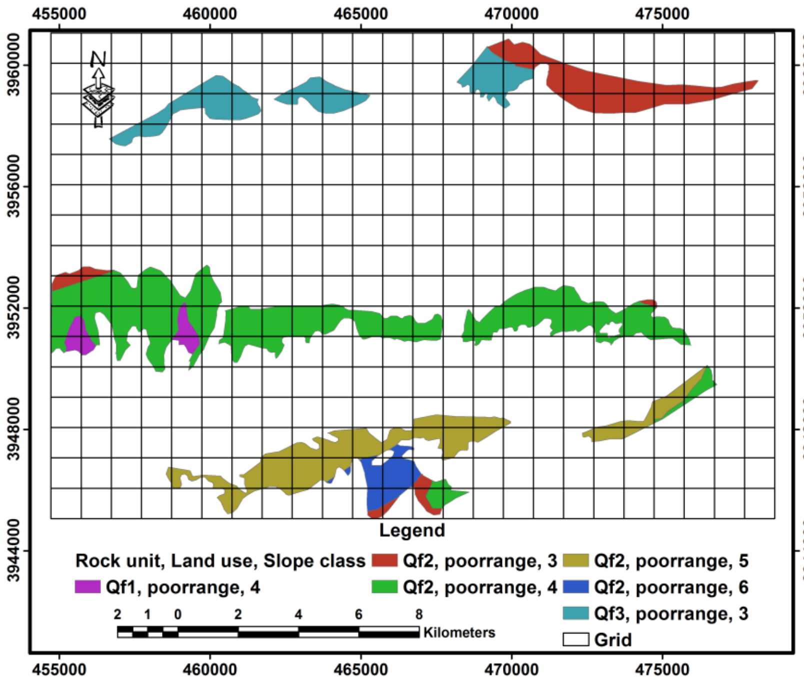

Fig. 5. Map of work units, south east of Roudeh-shoor watershed, Tehran province, Iran

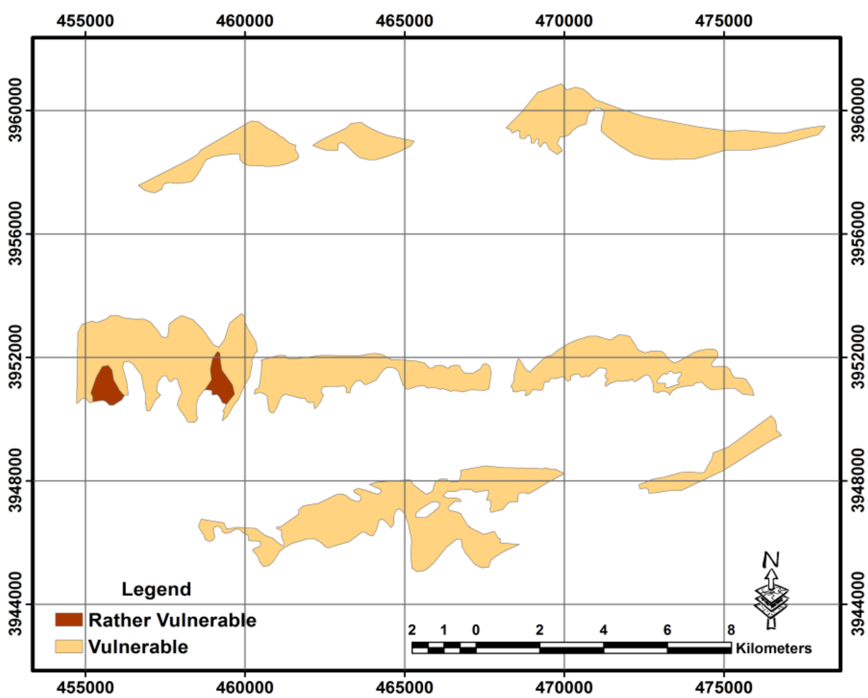

Fig. 6. Zonation map of resistance coefficient to erosion, south east of Roudeh-shoor watershed, Tehran province, Iran

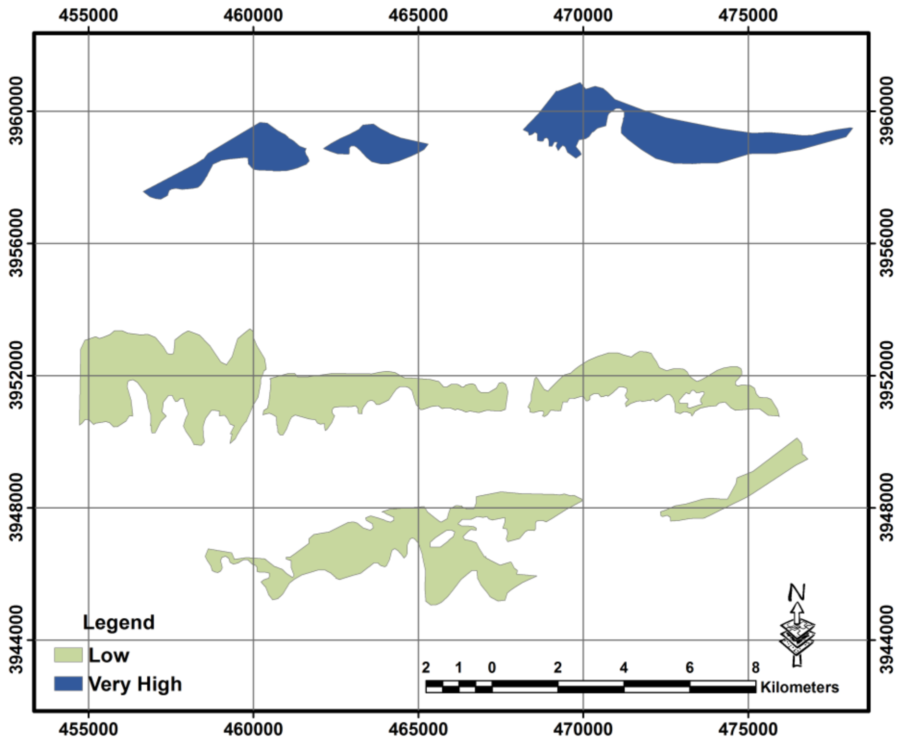

Fig. 7. Zonation map of salinity

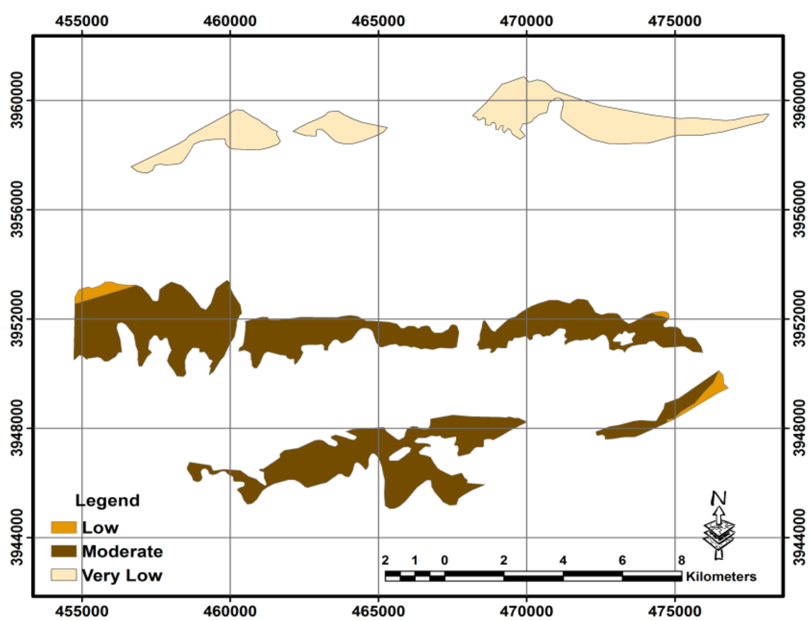

Fig. 8. Zonation map of permeability coefficient

Table 3. Mean values of criteria in each unit of research area, southeast of Roudeh-shoor watershed, Tehran province, Iran

Resistance Coefficient To Erosion		Salinity		Permeability		Area (ha)	Unit number
Quantitative amounts (Dimensionless)	Qualitative class	Mmhouse.cm-1	Qualitative class	m.day-1	Qualitative class		
3	Vulnerable	12.430	Very High	0.614	Very Low	679	1
3	Vulnerable	11.270	Very High	0.718	Very Low	239	2
3	Vulnerable	9.480	Very High	0.671	Very Low	193	3
3	Vulnerable	9.640	Very High	0.620	Very Low	367	4
4	Vulnerable	0.905	Low	19.230	Low	9	5
4	Vulnerable	0.746	Low	59.444	Moderate	708	6
4	Vulnerable	0.680	Low	68.114	Moderate	682	7
4	Vulnerable	1.002	Low	17.215	Low	69	8
4	Vulnerable	0.918	Low	51.825	Moderate	1047	9
5	Rather Vulnerable	0.730	Low	71.019	Moderate	73	10
5	Rather Vulnerable	0.881	Low	68.225	Moderate	80	11
4	Vulnerable	0.802	Low	53.030	Moderate	70	12
4	Vulnerable	1.030	Low	63.791	Moderate	249	13
4	Vulnerable	0.783	Low	12.201	Low	943	14
4	Vulnerable	0.880	Low	59.701	High	75	15
4	Vulnerable	1.096	Low	13.613	Low	57	16
4	Vulnerable	0.817	Low	11.822	Low	185	17

Weights of criteria and consistency Ratio derived from AHP was presented in Table 4. Since the consistency ratio is less than 0.1 ($CR \leq 0.1$), the values of subjective judgment are acceptable.

Table 4. Weights of criteria and consistency ratio derived from AHP

Criterion	Weight	Consistency Index (CI)	Random Inconsistency Index (RI)	Consistency Ratio (CR)
Resistance coefficient to erosion	0.221			
Salinity	0.685	0.027	0.580	0.047
Coefficient of permeability	0.093			

The relative closeness to the ideal solution obtained from AHP-TOPSIS technique alters from 0.016 to 1.000. Weighted Standardized Decision Matrix and Relative Closeness to the Ideal Solution have been presented in Table 5. According to the result, unit v1 has the most potential of desertification and unit v10 has the least potential of desertification with relative closeness to the ideal solution of 1.000 and 0.016, respectively.

Table 5. Weighted Standardized Decision Matrix and Relative Closeness to the Ideal Solution

Criterion	Options																
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17
Resistance coefficient to erosion	0.041	0.041	0.041	0.041	0.055	0.055	0.055	0.055	0.055	0.068	0.068	0.055	0.055	0.055	0.055	0.055	0.055
Salinity	0.391	0.354	0.298	0.303	0.028	0.023	0.021	0.032	0.029	0.023	0.028	0.025	0.032	0.025	0.028	0.034	0.026
Coefficient of permeability	0.000	0.000	0.000	0.000	0.010	0.031	0.035	0.009	0.027	0.037	0.035	0.028	0.033	0.006	0.031	0.007	0.006
d_i^+	0.000	0.036	0.093	0.088	0.363	0.369	0.371	0.360	0.363	0.371	0.366	0.367	0.360	0.367	0.365	0.357	0.366
d_i^-	0.372	0.336	0.280	0.285	0.026	0.014	0.014	0.028	0.016	0.006	0.008	0.015	0.018	0.028	0.015	0.030	0.029
R_i	1.000	0.902	0.750	0.764	0.067	0.036	0.037	0.072	0.042	0.016	0.021	0.038	0.047	0.072	0.040	0.079	0.073

In this step, classification of desertification potential of alluvial fans to be done using Arc GIS 10.3 and R_i values after joining the values to attribute table and limits presented in Table 6 (Fig. 9).

Table 6. Conspectus of integrative results of desertification potential classification in the research area

Class	Desertification Qualitative Potential	Desertification Quantitative Potential	Mean Of R_i Values	Limits Of R_i Value Changes
I	low	0.00-0.25	0.049	0.016-0.079
II	moderate	0.25-0.50	-	-
III	high	0.50-0.75	0.750	0.750
IV	Very high	0.75-1.00	0.889	0.764-1.00

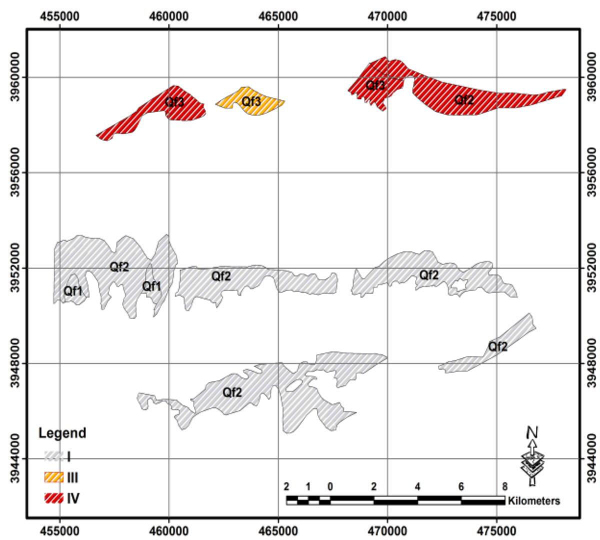

Fig. 9. Zonation map of desertification potential by AHP-TOPSIS

Also the overlaying and crossing the zonation map of desertification potential from the viewpoint of the pedological criterion in research area with geological map of research area, determined soil potential of alluvial fans from the viewpoint of the desertification potential in research area (Table 7).

Table 7. Soil potential of alluvial fans from the viewpoint of the desertification.

Class	Desertification Qualitative Potential	Rock Unit	Rock Unit Area (%)	Rock Unit Area (Ha)	Area (Ha)	Area (%)
I		Qf2	0.15	8.63		
		Qf2	12.37	707.86		
		Qf2	11.92	682.28		
		Qf2	1.20	68.62		
		Qf2	18.29	1046.57		
		Qf1	1.27	72.57		
	Low	Qf1	1.39	79.65	4245.77	74.18
		Qf2	1.22	69.98		
		Qf2	4.36	249.29		
		Qf2	16.48	943.01		
		Qf2	1.31	75.15		
		Qf2	0.99	56.74		
		Qf2	3.24	185.41		
III	High	Qf3	3.37	192.71	193	3.37
IV		Qf2	11.86	678.92		
	Very high	Qf3	4.18	239.22	1284.96	22.45
		Qf3	6.41	366.82		

4. Discussion

Obtained results showed that alluvial fans originated from different susceptible geological formations to erosion, such as marls, are in the very high desertification potential. These results are similar to results of Salehpour Jam (2006). Salehpour Jam (2006) introduced function of 0.8 from the fuzzy logic model for the desertification potential of kinds of rock units. According to the result of operator of 0.8 from the fuzzy logic model to zonate the area, rock units of Qf2 and Qf3 located in south of Halghe_Dareh have maximum potential of desertification in Roudeh-shoor watershed area. Karimpour Reihan *et al*. (2007) in the investigation of pedological criterion on land degradation in quaternary rock units showed that the potential of alluvial fans can alter in different classes of desertification potential in the south part of the Roudeh-shoor watershed area. Feiznia and Nosrati (2007) in the investigation of the effect of parent material and land-use on soil erosion in Taleghan drainage basin showed that erodibility increases when lithology changes from basalt to alluvial deposits and finally gypsum.

Finally, it is important to note that the MCDM techniques can be also used to de-desertification alternatives. Sadeghiravesh et al. (2014) applied AHP-ELECTRE to prioritization of de-desertification alternatives in the Khezr Abad region, Yazd province. The authors suggest that the other methods of multi criteria decision making (MCDM) such as VIKOR, ELECTRE, etc. to be applied to show the effect of pedological criterion on desertification using GIS techniques.

5. Conclusion

The results of this research showed that the alluvial fans in research area were classified into three classes of I, II, and IV from the view point of pedological criterion affecting on desertification using AHP-TOPSIS technique. Obtained results showed that 74.18 % of the area is in the low desertification potential, and 3.37 % and 22.45 % are in the high and very high desertification potential, respectively. Obtained results from AHP method also showed that the most important factor affecting on land degradation and desertification is salinity. The other factors such as Resistance coefficient to erosion and coefficient of permeability have less importance, respectively.

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