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Determination of erodible areas using MCDM models in the east of Iran

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ABSTRACT

In order to achieve sustainable land management, there is a need to comprehensively investigate the factors affecting soil erosion. If there are critical areas in terms of SE in a watershed, by accurately identifying them, it will be possible and reasonable to control and fight against erosion. This research, used Multi-Criteria Decision Making models include AHP, ANP, and BWM in the GIS environment to determine the erosion prone areas. First, the effective factors on erosion were determined based on the opinions and case studies conducted in the area. In the following, the desired data were obtained from relevant organizations, field observations, and previous datasets. In the next step, questionnaires on the impact of criteria on erosion were sent to experts, and after completing the questionnaires, the relative importance of criteria was obtained in Expert Choses and Supper Decision software's. Next, maps were prepared and combined. Finally, the erosion-susceptibility map of the region was obtained. The results showed that the geological formation factor had the significant effect on the erodibility with a relative importance of 0.23. In the following, the area was classified into five classes in terms of sensitivity to erosion, and the areas with high sensitivity have the largest area. The results of the MADM models used in this research were evaluated using the MPASIC experimental method, which all were suitable, so they are capable of determining erosion-prone areas.

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1. Introduction

Soil is a key resources for the humankind (Keesstra *et al.,* 2016, 2018a). Agricultural production and renewable natural resources of watersheds, including soil and water resources, were endangered by SE. Following this phenomenon, we can expect many adverse consequences, which in turn will severely affect the social and economic sectors (Schwab, 1993). Given the fact that SE reduces soil fertility and intensifies sediment production and increases the likelihood of flooding, the human food security is subject to a threat (Soyoung *et al.,* 2011). In most of countries, management and control of SE can only be undertaken by incurring a high cost (Eswaran *et al.*, 2001). Therefore, identifying the susceptible areas to erodibility makes this possible to prioritize the different areas within a watershed in accordance with their potential of erodibility. Correspondingly, a cost-effective approach can be adopted for implementing a precise (Farhan *et al.,* 2017, Arabameri *et al.*, 2018). Generally, several parameters and variables involve in the natural SE process such as precipitation (type and intensity), slope, land cover, land use, geology, and vegetation cover. (Moore and Burch, 1986; Mitasova *et al.,* 1996). Human activities such as mining can accelerate this process more than the natural phenomenon of SE. Thus owing to the involvement of many factors affecting on SE, the vulnerability of all areas to erodibility would be heterogeneous (Biswas *et al.,* 1999). Since some of these factors are difficult to be quantified and are not well spatially characterized, ascertaining and prioritizing these factors in terms of being effective on the SE process pose a formidable challenge (Nelson et al., 2014; Bensekhria and Bouhata, 2022). To address this challenge, several studies have taken advantages of Geographical Information System (GIS), through which a data collection on the spatial distribution of erosion and its related factors are effectively possible and therefore, the spatial map of erosion severity can be created (Singh and Panda 2017). To that regard, MCDM methods have also been designed by a wide range of soil and water studies (Joubert *et al.,* 2003; Alamanos *et al.,* 2018; Manikkuwahandi *et al.,* 2019, Saha *et al.*, 2019; Meshram *et al.,* 2022; Ouali *et al.,* 2023). The advantages and disadvantages of this approach for such a purpose have been well discussed (Saaty 1977; 1999; Taha and Rostam 2012; Kumar and Sarkar 2022). To benefit from both GIS and MCDM, while reducing their limitations, an integrated scheme has been developed (Suling *et al.*, 2010; Zhang *et al.,* 2012; Bagheri *et al.,* 2022; patel *et al.,* 2023). In the light of this integrated scheme, one can efficiently determine the susceptible regions to SE and thereby prioritizing the regions (Keesstra *et al.,* 2018b; 2021).

In this study, MCDM methods include Analytical Hierarchy Proses (AHP), Analytical Network Proses (ANP), and Best Worst Method (BWM) to prepare a quantitative assessment map of soil erosion (SE) vulnerability to water in Bagheran Birjand watershed located in the east of Iran.

2. Materials and methods

2.1. Study area

The geographical position of the Bagheran watershed extends from 58° 05′ to 59° 11′ E longitude and from 32° 43′ to 32° 51′ N latitude. It is in the South Khorasan province in eastern Iran (Figure 1). In general, the total area of Baghran watershed is 119 square kilometers. The average annual rainfall is 188 mm and the average temperature of the watershed is 13.5 degree Celsius.

2.2. Methodology

Identifying areas prone to erosion by performing MCDM in GIS environment has become popular due to the higher efficiency and at the same time lower cost that this combination brings to the operation (Arabameri *et al.*, 2018). This combination is comprehensive approaches designed for MCDM with multiple criteria, because it can provide a hierarchical tree (purpose, criteria and options), normalize the inputs and synthesize the obtained results (Triantaphyllou 2000). For this purpose, in addition to designing a GIS based MCDM model, this study took advantages of hierarchical analysis and network analysis process.

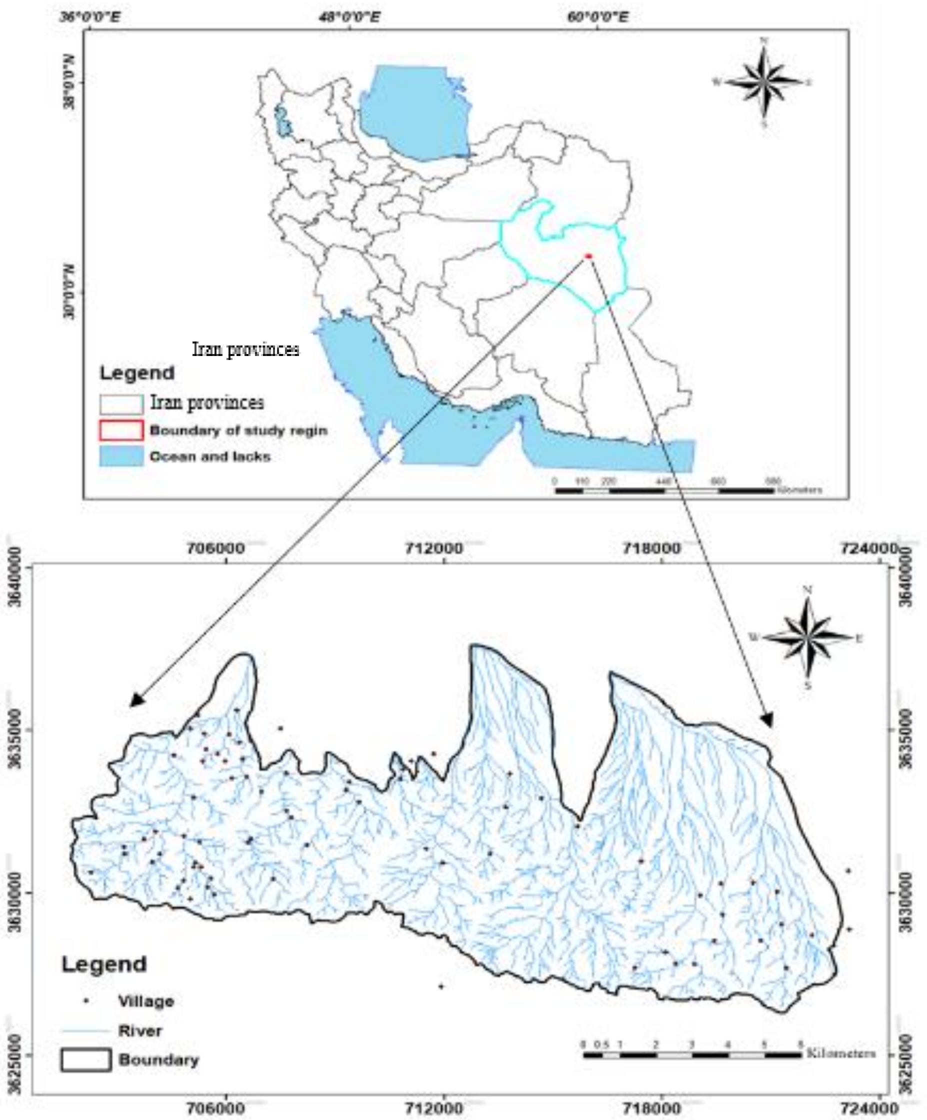

Fig. 1. Geographical location of the study area

To that end, firstly, the factors affecting the erosion process and rates in this watershed were determined using a field survey and literature reviews of the previously conducted studies for this watershed.

Study area data were obtained from various sources, including: (i) DEM from NASA's Satellite with 1-arcsecond resolution (approximately 30 m) spatial resolution, (ii) precipitation data from Iran Meteorological Organization (IRIMO), (iii) land use and soil map from the Ministry of Agriculture of Iran with a scale of 1:100,000 in 2020, (iv) geology map from Geological Survey & Mineral Explorations of Iran (GSI) with a scale of 1:100,000 in 2000, and (v) field surveys conducted by authors.

In the next step, the relative importance of each criterion was completed by experts with 25 questionnaire items. The experts then completed 21 questionnaires, all questionnaires were aggregated using geometric mean, the final questionnaire was entered into Supper Decision software to obtain the final weight (Saaty 1977; Schwab *et al.*, 1993). Based on the final weight, the effect of the criteria on erosion is determined. A map of all criteria was prepared in the GIS environment. Then all the criteria maps were aggregated in the Raster Calculator in GIS environment. Thus, the susceptibility map was determined based on all three methods (AHP, ANP and BWM). The MPSIAC (Modified Pacific Southwest Inter-Agency Committee) method, a field method to estimate the amount of erosion, was used to evaluate the results (Fig 2).

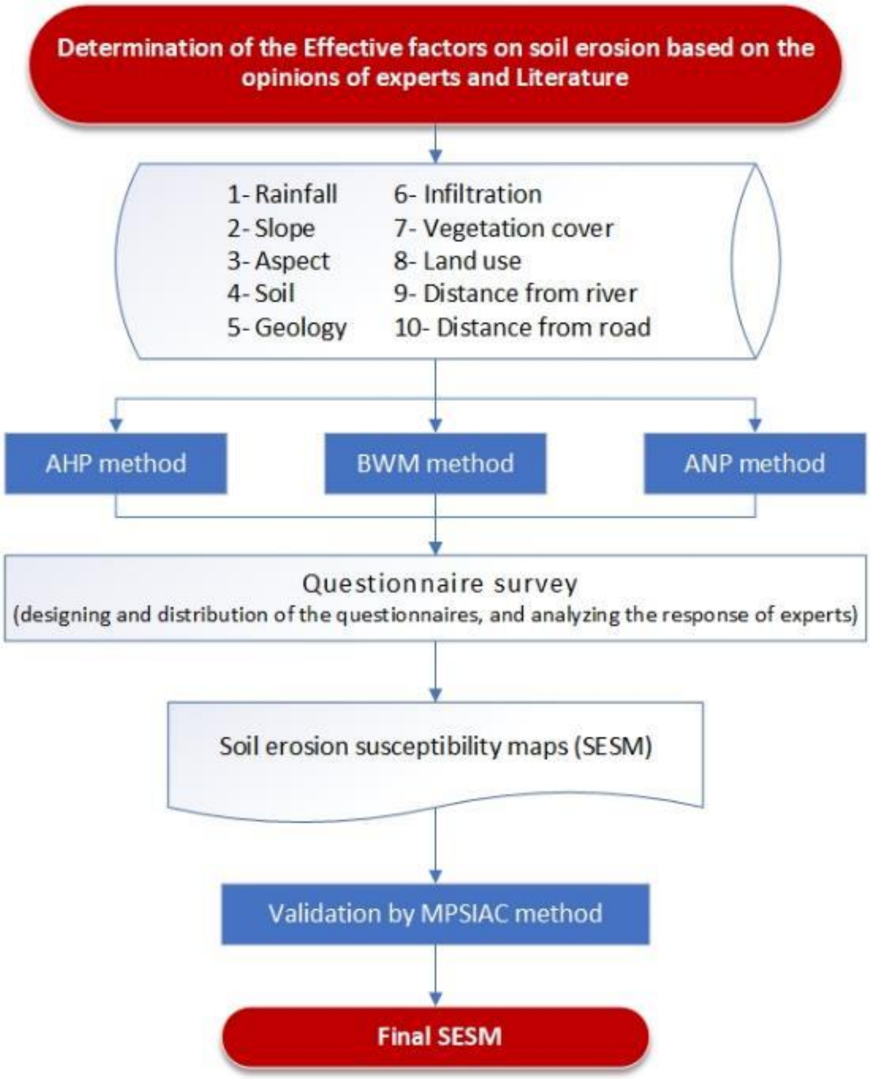

Fig. 2. Methodology flowchart

2.2.1. AHP method

AHP is one of the MCDM techniques that was first presented by Thomas El Saaty in the 1970s (Saaty 1977). This method looks at complex issues hierarchically and turns complexity into simplicity. Hierarchical analysis process can be used when there is competition between several alternative and criteria in the decision making process. Criteria can be quantitative and qualitative. The steps are: (i) Determining criteria and indicators, (ii) Pair comparisons, (iii) Determining incompatibility rates, and (iv) Determining final weight of criteria and indicators.

Determining inconsistency rates

Almost all the calculations for AHP are based on the decision maker's initial judgment, which appears in the pairwise comparisons matrix, and any errors and inconsistencies in comparing and determining the significance of the resulting calculus options and indices. It is therefore necessary to determine the incompatibility rate, which includes the 5 steps:

Step 1: Computing the Weighted Total Vector: Multiply the Matrix of Comparative Pairs in the "Relative Weight" column vector.

Step 2: Compute the consistency vector. Then, the elements of the weight vector were divided by the relative priority vector. Therefore, the resulting vector is called the consistency vector.

Step 3: Obtain λ max that gives the mean of λ max consistency vector elements. Step 4: Calculate consistency index according to the following equation 1:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{1}$$

Where λ_{max} is the largest Eigen value of the matrix.

Step 5. Calculation the consistency ratio (CR) by dividing the consistency index by random attribute, equation 2:

$$CR = \frac{CI}{CR} \tag{2}$$

where RI represents the consistency index, which depends on the dimension of the matrix order provided by Saaty (1980). The maximum acceptable CI is 0.1 (Malczewski 1999).

2.2.2. ANP method

ANP has been introduced by Thomas L. Saaty (1999) to resolve the AHP constraint. In this method, the relationship between the elements of the decision matrix replaces the hierarchical structure. This method is, in fact, the general state of the AHP and its broader form in which issues of interdependence and feedback can also be considered.

1- Determining criteria and indices, specifying clusters and elements 2- Determining the relationships and dependencies between elements of above communication in clusters and elements in Super Decisions software 3- Weighting and pairwise comparisons of the elements using the questionnaire determination of inconsistency ratio (IR). 4- Factor coefficient and final weight of criteria through the matrix and normalization process.

2.2.3. BWM method

Step 1: Determining criteria. Step 2: In this step, determine the most important and least important criterion of all the indices. Step 3: Then compare the best criteria (BO) paired criteria with the other criteria, those pairwise comparisons by the 1 to 9-hour range. Step 4: It should be compared with the other criteria with worst-case criteria. Those pairwise comparisons by the 1 to 9-hour range. Step 5: The optimal weights should be determined (W*1, W*2, …, W*n) (Rezaei 2016).

2.2.4. Water erosion factors

Rainfall: Rainfall erosivity is a parameter that indicates the erosion potential of the soil by rainfall, also the sediment is affected by the amount and intensity of rainfall, and high rainfall areas are more sensitive to rainfall than low rainfall areas (Arabameri *et al.*, 2017).

Slope: The slope factor is the important parameters affecting SE (Pal 2016), which has a direct relationship with erosion so that with increasing slope, SE also increases. **Aspect:** The aspect directly and indirectly affects the amount of erosion (Ren *et al.*, 2018).

Soil: Different soils have different susceptibility to erosion due to the amount of slope and its physical and mechanical properties (Saha *et al.*, 2019).

Geology: Lithological features in watersheds are among the factors that control erosion. By determining the resistance of rocks and formations, different zones can be classified according to erosion (Rahmati *et al.*, 2017).

Permeability: Permeability is one of the effective factors in runoff control which has inverse relationship with SE, thus decreasing the amount of water erosion with increasing permeability (Chezgi *et al.*, 2016).

Vegetation cover or land cover: The vegetation factor directly and indirectly affects SE, making vegetation less vulnerable to fallow and barren land, and preventing rainforest and grassland. The soil erodes (Sadoddin *et al.*, 2010).

Land use: Erosion depends a lot on the type of land use. The change of land use, especially the reduction of forest and pasture lands and their conversion to agricultural, commercial and residential uses, and as a result, the increase of floods and the increase of annual sedimentation implies this (Saha *et al.*, 2019).

Distance from the river: Bank erosion and gully erosion accorded around the river so the region that near the river have a more potential for erosion (Ebrahimi *et al.*, 2021).

Distance from road: Distance from the road is one of the criteria that effect on erosion in the creation and after of construction with canalization and concentration water to erosion the soil. Other view increase compaction so increases the runoff (Forzieri *et al.*, 2008) (Fig 3).

Table 1. Generating different layers of data

No.	Parameters	Notation	Techniques	References
1	Annual Rainfall (MM)	R	$R = \sum_{i=1}^{12} 1.735 \times 10 \left[1.5 \log_{10}\left(\frac{P^2}{p}\right)\right] - 0.08188$	Hijmans *et al* 2005
2	Slope degree	S	$Tan\theta = \frac{N \times 1}{636.6} N = N_o.\ of\ Contour\ Cutting;$ $i = Contour\ Interval$	Wentworth 1930
3	Aspect	A	-	Saha *et al* 2019
4	Soil	So	Reference sheet	Saha *et al* 2019
5	Geology	G	Reference sheet	Rahmati et al, 2017
6	Infiltration	I	Reference sheet	Chezgi *et al* 2016
7	Vegetation cover (NDVI)	V	NDVI=$\frac{NIRBAND - IRBAND}{IRBAND + IRBAND}$	Carlson and Ripley 1997
8	Land use	Lu	Maximum likelihood	Anderson 1971
9	Distance of River	Dri	Proximity analysis	Pavelsky and Smith 2008
10	Distance of Road	Dro	Proximity analysis	Forzieri et al, 2008

After obtaining the relative importance of the criteria in both methods (table 2 and 3), maps should be prepared to determine the erodible areas, and by applying this relative importance and integrating the maps for each individual model, the final erosion zoning map based on followed equation was made.

Erosion = (w1 x C1) + (w2 x C2) + (w3 x C3) +… + (w10 x C10) (3)

Where w1 = weight of criteria 1, w2 = weight of criteria 2 and up to w10 = weight of criteria 10. C1 = criteria 1, C2 = criteria 2, C3 = criteria 3 and up to C10 = criteria 10.

Table 2. Influential criteria and Impressive criteria in ANP method

Influential criteria	Impressive criteria
Rain	Vegetation Cover
Soil	Vegetation Cover, Infiltration, Landuse
Slope	Infiltration, Landuse
Geology	Vegetation Cover, Infiltration, Landuse
Infiltration	Vegetation Cover

Table 3. Weight of criteria in AHP method

Parameters	Annual rainfall	Aspect	Soil	Geology	Slope	Distance of Road	Distance of River	Infiltration	NDVI	Land use	Weight
Annual rainfall	1.00	5.00	2.00	3.00	1.00	4.00	4.00	2.00	3.00	3.00	0.21
Aspect	1/50	1.00	2.00	0.33	0.25	0.50	0.50	0.25	0.33	0.33	0.04
Soil	1/20		1.00	1.00	0.50	2.00	2.00	1.00	1.00	1.00	0.08
Geology	1/30			1.00	0.50	3.00	3.00	1.00	2.00	2.00	0.12
Slope	…				1.00	3.00	3.00	2.00	2.00	2.00	0.17
Distance of Road						1.00	1.00	0.50	0.50	0.50	0.05
Distance of River							1.00	1.00	1.00	1.00	0.05
Infiltration								1.00	1.00	1.00	0.10
NDVI									1.00	1.00	0.09
Land use										1.00	0.08

2.2.5. Assessment method

MPSIAC models used for assessment the AHP and ANP methods in this study. MPSIAC models is the modified PSIAC method (Johnson and Gembhart 1982), which based on field survey and expert data. That include 9 parameters (surface geology, soil, climate, runoff, slope vegetation and land use, present SE) in erosion intensity (Refahi 2009, Ahmadi 2011) (table 4).

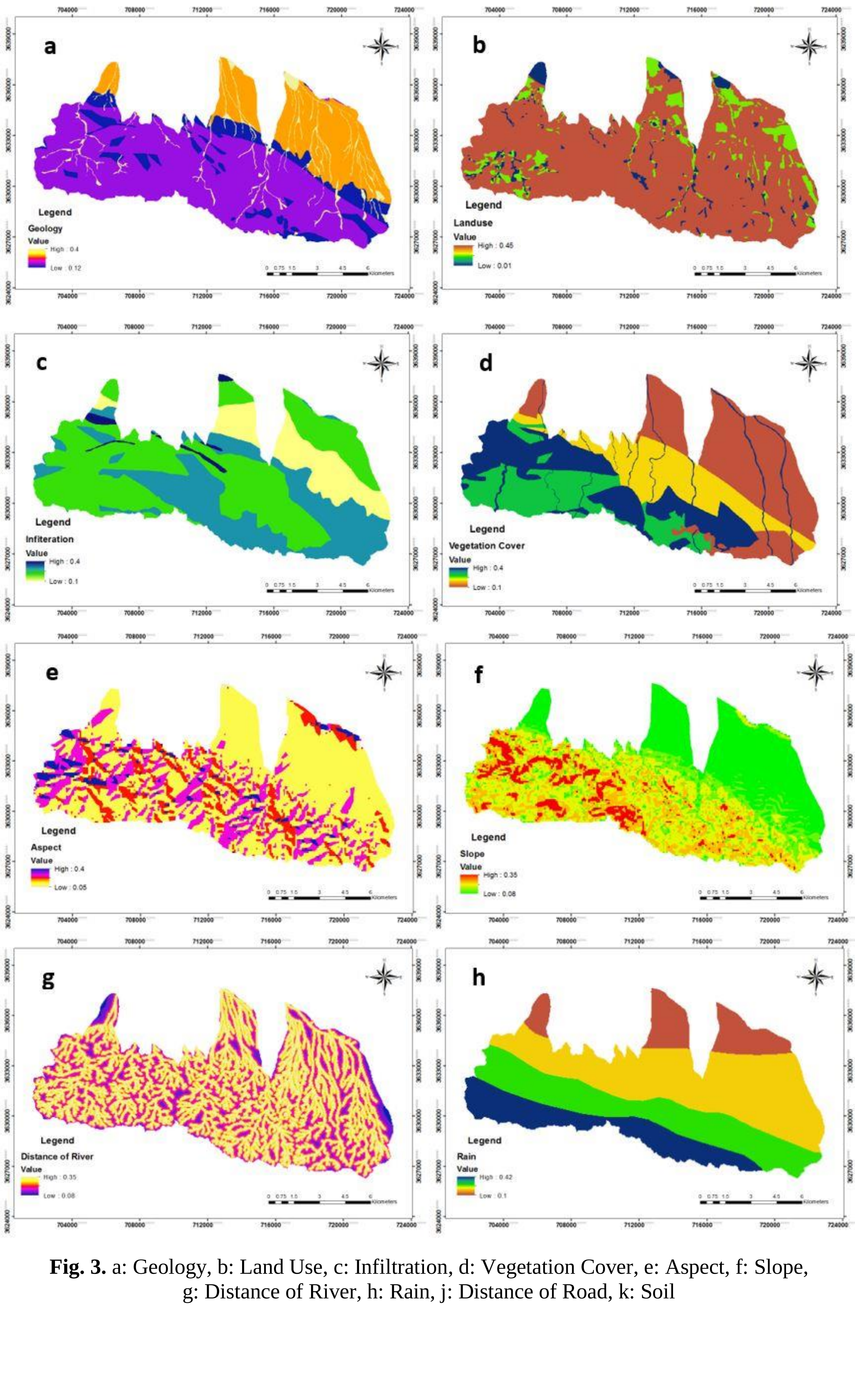

Fig. 3. a: Geology, b: Land Use, c: Infiltration, d: Vegetation Cover, e: Aspect, f: Slope, g: Distance of River, h: Rain, j: Distance of Road, k: Soil

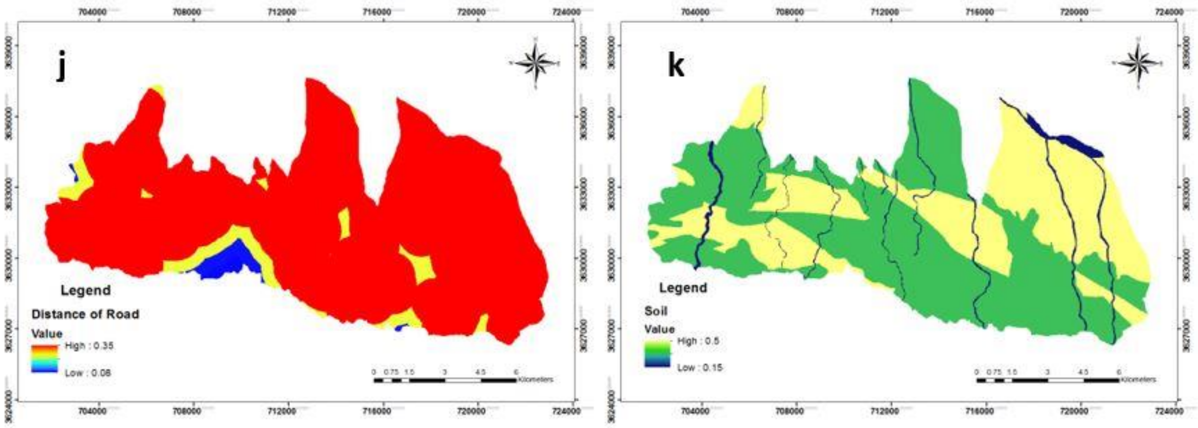

Fig. 3. Continued

Table 4. MPSIAC model description (Pourkarimi *et al.*, 2018)

Factors	Calculated points	Definitions
Geology	$Y_1=X_1$	X_1: stone sensitive point
Soil	$Y_2=16.6K$	K: erodibility factor in USLE
Climate	$Y_3=0.2X_3$	X_3: precipitation intensity with 2-year interval return
Water runoff	$Y4=0.006R+10Q_p$	R: annual runoff depth (mm), Q_p: annual specific discharge (CmS/km^2)
Topography	$Y_5=0.33S$	S: average watershed slope (%)
Land cover	$Y_6=0.2X_6$	X_6: bare soil (%)
Land use	$Y_7=20-0.2X_7$	X_7: canopy cover (%)
Surface erosion	$Y_8=0.25X_8$	X_8: points summation in BLM model
Gully erosion	$Y_9=0.16X_9$	X_9: point of Gully erosion in BLM model

3. Results

According to the results listed in Table 5, based on the expert opinions quantified in the AHP method, the rain and aspect criteria with the relative importance of 0.21 and 0.044 were found to have the maximum and minimum effect on determining the susceptible areas to SE, respectively. Similarly, in accordance with the ANP algorithm, the results (Table 5) demonstrated that the vegetation and geological criteria with the relative importance of 0.158 and 0.054 had the biggest and smallest impact on identifying the vulnerable areas to erosion, respectively. Due to the fact that the ANP method identifies the relationships between the criteria and whose effects on one another, the relative importance obtained from this method varies widely from that of the AHP method as the latter functions independently and thus not taking into account the relationship among the criteria.

Furthermore, results indicated that (Table 5) the rain factor with the relative importance of 0.172 was the most effective in ascertaining the susceptible areas to the SE, while the distance from the road, as quantified with the criteria of relative importance of 0.021, exerted the least influence on the SE, based on the expert opinions in the AHP method.

Following the determination of the criteria weights, the susceptibility maps to the SE was prepared for each of the applied methods in the ArcGIS environment (figures 4-7), and the procured area for each of the vulnerability classes was listed in Table 6.

Table 5. Criteria Weight in AHP, ANP and BWM methods

Variables	Weight in AHP Method	Weight in ANP Method	Weight in BWM Method
Annual rainfall	0.210	0.060	0.172
Aspect	0.044	0.062	0.039
Soil	0.084	0.119	0.116
Geology	0.117	0.054	0.096
Slope	0.170	0.057	0.135
Distance of Road	0.049	0.107	0.021
Distance of River	0.050	0.117	0.115
Infiltration	0.099	0.131	0.094
NDVI	0.086	0.158	0.154
Land use	0.085	0.134	0.058

As shown by table 6 and figure 8, the area fallen into the moderate class covers the largest part of the watershed, irrespective of the method used. While, each of the other classes covers a small area (Table 6). Therefore, each of the methods could plausibly estimate the areas fallen into each class. Of which, the BWM method showing a strong correlation with the MPSIAC model, that is 0.9, yielded the best estimation (Table 6).

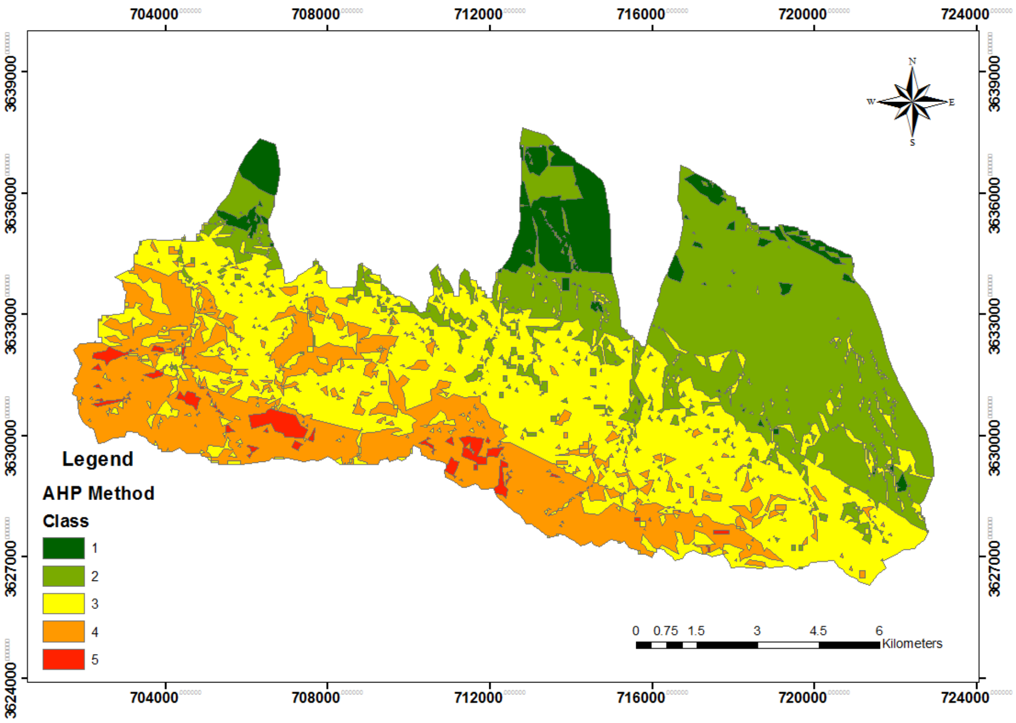

Fig. 4. The susceptibility map to the SE prepared using the AHP method

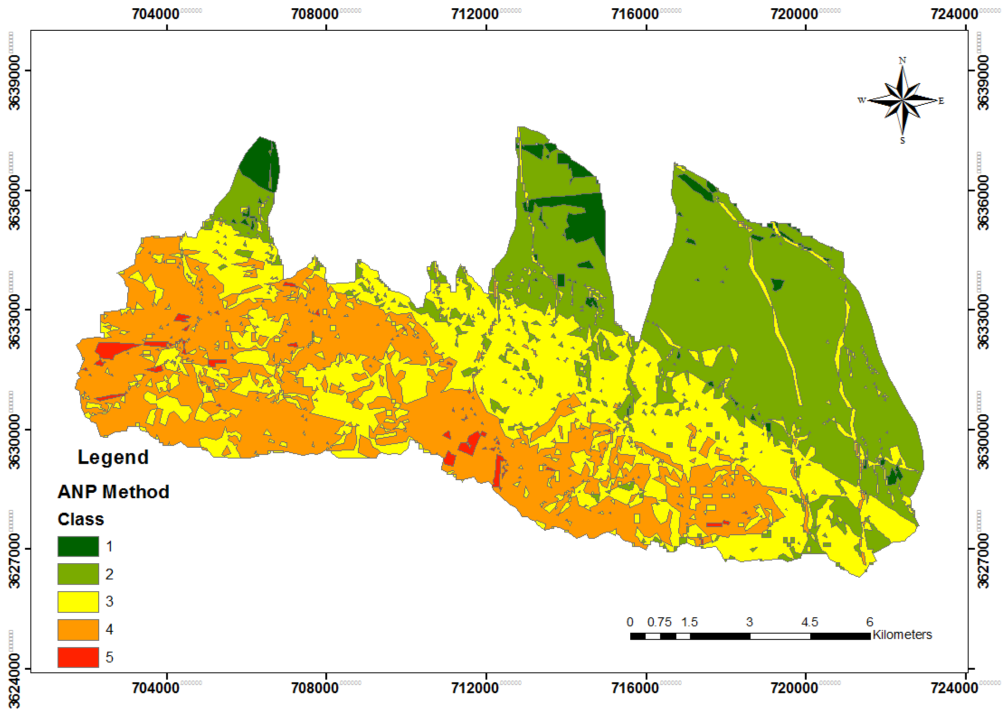

Fig. 5. The susceptibility map to the SE prepared using the ANP method

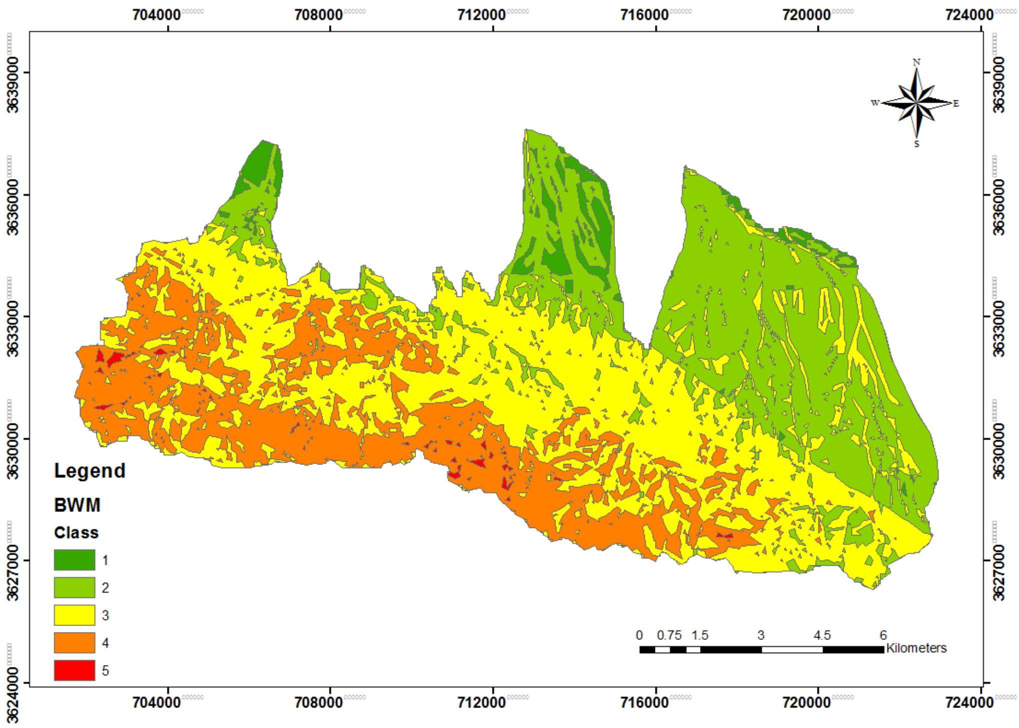

Fig. 6. The susceptibility map to the SE prepared using the BWM method

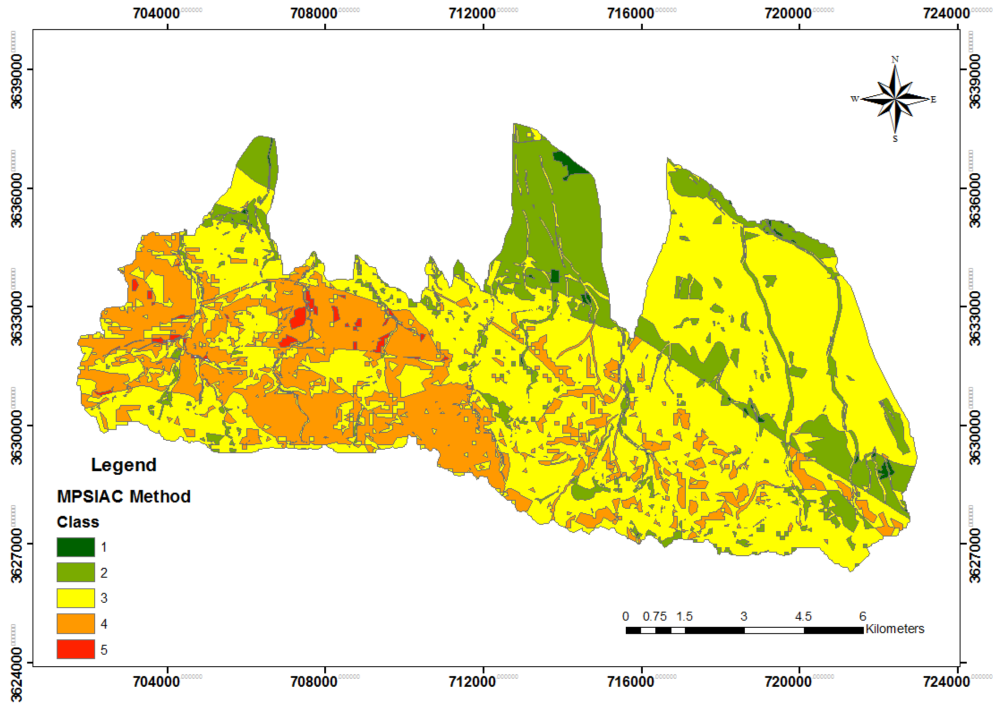

Fig. 7. The susceptibility map to the SE prepared using the modified MPSIAC model

Table 6. The area of each class in each model and its evaluation with the MPSIAC model

Erosion Class	ANP (ha)	AHP (ha)	BWM (ha)	MPSIAC (ha)
Very low (Class 1)	273	795	381	71
Low (Class 2)	4058	4031	3924	2199
Moderate (Class 3)	4402	5070	5476	7736
High (Class 4)	4298	3057	3291	3059
Very High (Class 5)	121	199	57	88
Correlation with MPSIAC	0.77	0.87	0.90	1

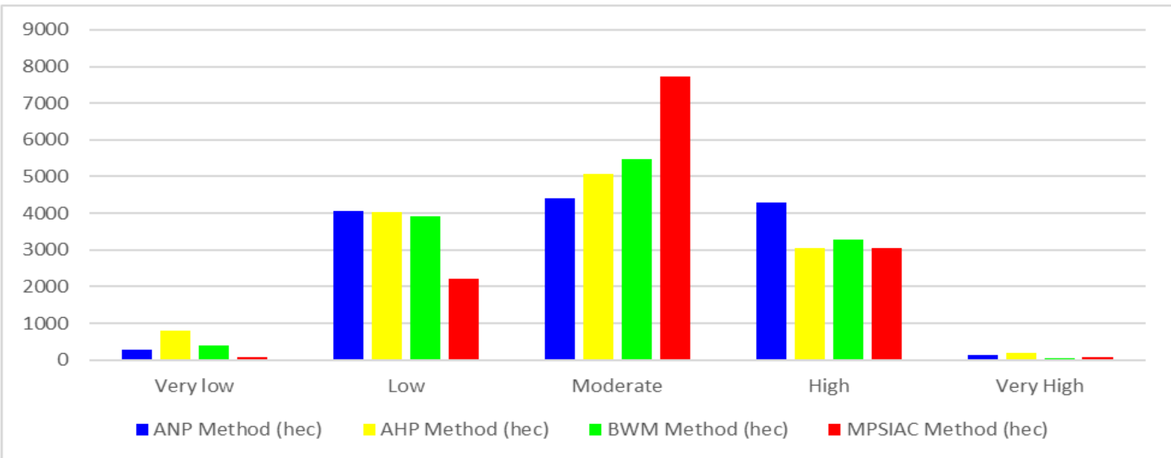

Fig. 8. Erosion class area estimated by all methods

4. Discussion

The results of AHP and BWM methods, as listed in Table 5, showed that the rain criterion with AHP and priority respectively 0.21 and 0.172, agree with the findings of Saha et al (2019). Moreover, finding showed that the slope factor with AHP priority 0.18 indicated a direct correlation with the SE which is also corroborated by the study of by Tucker and Bras (1998) and Safari et al (2015). We have found that the geology criterion with AHP priority 0.117 had the most important effect on the soil erodibility according to the survey statistic resulted from the expert's opinions, which is consistent with the results of Gernami and Shadfar (2018) and Choubin et al (2017). The experts' opinions demonstrated that the distance from the river and road, with the relative importance of 0.05 and 0.049 respectively, had the smallest impacts on the soil erodibility which is not consistent with the results of Gernamy and Shadfar (2018), they found the distance from the road to be the most influential criterion. It is worth mentioning that the distance from the river criteria have thus far not been used to determine the erodibility of an area in previsions studies.

The results of the ANP method (Table 2) showed that there are mutual interactions between the parameters influencing the SE and this can be estimated using the ANP method. Such a relationship has not been documented by previous studies thus far. Thus, it is of paramount importance to characterize the relationship among the parameters affecting on the SE. For example, according to Table 2, the rainfall factor affects the vegetation cover, and the latter itself can increase or decrease soil erosion, depending on its condition, which is consistent with the results of Gernami and Shadfar (2018). In the current study, the geological factor has found to be correlated with most of the other criteria used in this study, including infiltration, vegetation cover, and land use.

The results of ANP method in Table (5) showed that the vegetation and land use criteria with the relative importance of 0.158 and 0.134 respectively had the greatest impact on erosion according to the experts' opinion in the ANP method. That places a particular emphasis on the vegetation cover role on controlling the SE (Saha *et al.*, 2019).

Table 7 revealed that according to the modified PSIAC method, nearly 60% of the watershed area fall into the middle class, while with respect to the findings of the AHP and ANP approaches 38% and 33% of the domain area were categorized as the middle class, respectively. This indicates that decision-making models estimated a small area to be categorized under the low and high classes of susceptibility to erosion. Thus, the ANP method can produce a promising result for the high and low classes, while the AHP method is better for the middle class.

5. Conclusion

The purpose of this research is to determine erosion-prone areas using decision-making models in areas without sediment measurement stations and quantitative data on erosion. Based on this, experts' opinions were used and effective parameters in erosion were determined. Next, the parameter map was prepared in GIS environment and combined based on the value of each parameter.

The final map of erosion susceptibility results suggested that the middle class of sensitivity with a size of 7736 hectares covers the greatest extent compared with the other classes such as the very low class with an area of 71 hectares. The results illustrated that the mountainous areas of the region, located in the south and southwestern part of the basin, are the most susceptible to erosion due to their steep slope.

The middle class of vulnerability to the SE covers approximately 50% of the watershed area studied in Iran. However, if proper and effective watershed management measures as well as soil conservation practices are not taken into consideration for this class of proneness to erosion, a large amount of SE and thus sediment yield can be generated, given the size of this class. Considering a proper management of the area, the susceptibility of the middle class will be decreased, which in turn more than 70% of the watershed area will turn out to a low class of vulnerability.

SE occurs approximately in all of the Iran’s hydro-climate regions, as a result, it can threaten the food security on a national scale. Several different methods have been developed for estimation of the SE rate. In spite of that, there is no consensus on a specific model/approach for an accurate estimation of SE. Given the paucity of high quality and long-term monitoring of parameters affecting on SE in Iran, taking advantages of the experts’ opinion, analyzed and interpreted by advanced methods such as AHP, ANP and BWM, can be of great help; the fact that was taken into account in the present study.

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References

Ahmadi, H., 2011. Applied Geomorphology. University of Tehran Publications. 735 pp.

Alamanos, A., N. Mylopoulos, A. Loukas, D. Gaitanaros, 2018. An integrated multicriteria analysis tool for evaluating water resource management strategies. Water, 1795-1810. doi: 10.3390/w10121795

Anderson, J.G., 1971. Rocket measurement of OH in the mesosphere. J Geophys Res., 76(31); 7820–7824.

Arabameri, A.R., H.R. Pourghasemi, A. Cerda, 2017. Erodibility prioritization of sub-watersheds using morphometric parameters analysis and its mapping: a comparison among TOPSIS, VIKOR, SAW, and CF multi-criteria decision making models. Sci Tot Environ., 613–614; 1385–1400.

Arabameri, A., B. Pradhan, H.R. Pourghasemi, K. Rezaei, 2018. Identification of erosion-prone areas using different multi-criteria decision-making techniques and GIS. Geomat Nat Haz Risk, 9; 1129–1155. doi:10.1080/19475705.2018.1513084

Bagheri, S., M. Ansari, A. Norouzi, 2022. Prioritization of Erosion Prone Sub-Watersheds using MCDM Methods in Roudzard Watershed, Khuzestan Province. JWSS, 26(3); 35-54.

Biswas, S., S. Sudhakar, V.R. Desai, 1999. Prioritization of sub-watersheds based on morphometric analysis of drainage basin: a remote sensing and GIS approach. Journal of the Indian Society of Remote Sensing, 27; 155–166.

Carlson, TN., D.A. Ripley, 1997. On the relation between NDVI, fractional vegetation cover, and leaf area index. Remote Sens Environ., 62(3); 241–252.

Chezgi, J., H.R. Pourghasemi, S.A. Naghibi, H.R. Moradi, M. Kheirkhah Zarkesh, 2016. Assessment of a spatial multi-criteria evaluation to site selection underground dams in the Alborz Province, Iran, Geocarto International, 31(6); 628-646. https://doi.org/10.1080/10106049.2015.1073366

Choubin, B., O. Rahmati. N. Tahmasebipour, B. Feizizadeh, HR. Pourghasemi, 2017. Application of fuzzy analytical network process model for analyzing the gully erosion susceptibility; Natural Hazards GIS-based Spatial Modeling Using Data Mining Techniques. Springer International Publishing. Chapter 11, 21 p.

Ebrahimi, J., H.R. Moradi, J. Chezgi, 2021. Prioritizing suitable locations for underground dam construction in south-east of Bushehr Province. Environmental Earth Sciences, 80(19); 680. https://doi.org/10.1007/s12665-021-09978-9

Eswaran, H., R. Lal, P.F. Reich, 2001. Oldeman, Penning de vries, F.W.T, Scherr, S.J, Sombatpanit, S. 2018. Response to land degradation, science publishers Inc, Enfield, USA. 21pp.

Farhan, Y., A. Anbar, N. Al-Shaikh, R. Mousa, 2017. Prioritization of semi-arid agricultural watershed using morphometric and principal component analysis, remote sensing, and GIS techniques, the Zerqa River Watershed, Northern Jordan. Agric Sci., 8; 113-148.

Forzieri, G., Gardentim, M. Caparrini, F. Castelli, F, 2008. A methodology for the preselection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Mali, Physics and Chemistry of the Earth. 33(1); 74-85.

Haokip, P., M.A. Khan, P. Choudhari, LC. Kulimushi, I. Qaraev, 2022. Identification of erosion-prone areas using morphometric parameters, land use land cover and multi-criteria decision-making method: geo-informatics approach. Environ Dev Sustain., 24**;** 527-557. https://doi.org/10.1007/s10668-021-01452-7.

Hijmans, RJ. SE. Cameron, JL. Parra, PG. Jones, A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. Int J Climatol a J Royal Meteorol Soc., 25(15); 1965-1978.

Jhonson, C.W., A.C. Gembhart, 1982. Predicting sediment yield from Sagerbrush range lands. USDA SEAARM Western Series 26; 145-156.

Joubert, A., T.J. Stewart, R. Eberhard, 2003. Evaluation of water supply augmentation and water demand management options for the city of Cape Town. J. Multicriteria Decis. Anal., 12; 17-25. doi: 10.1002/mcda.342

Kumar, P., P.A. Sarkar, 2022. Comparison of the AHP and TOPSIS multi-criteria decision-making tools for prioritizing sub-watersheds using morphometric parameters' analysis. Model. Earth Syst. Environ., 10(1); 542-558. https://doi.org/10.1007/s40808-021-01334-x

Keesstra, S. D., J. Bouma, J. Wallinga, P. Tittonell, P. Smith, R.D. Bardgett, 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil, 2; 111-128

Keesstra, S., G. Mol, J. de Leeuw, J. Okx, M. de Cleen, S. Visser, 2018. Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work. Land, 7(4); 133-151

Keesstra, S., S. Sannigrahi, M. López-Vicente, M. Pulido, A. Novara, S. Visser, Z. Kalantari, 2021. The role of soils in regulation and provision of blue and green water. Philosophical Transactions of the Royal Society B, 376(1834); 20200175.

Keesstra, S., J. Nunes, A. Novara, D. Finger, D. Avelar, Z. Kalantari, A.erdà, 2018. The superior effect of nature based solutions in land management for enhancing ecosystem services. Science of the Total Environment, 610; 997-1009.

Malczewski, J., 1999. A GIS-based approach to multiple criteria group decision making. Int J Geograph Inf Syst., 10; 955–971.

Manikkuwahandi, T.D.S., G.M. Hornberger, H. Baroud, 2019. Decision analysis for expansion of mahaweli multipurpose reservoir system in Sri Lanka. J. Water Resour. Plan. Manag., 145; 05019013. doi: 10.1061/ (ASCE) WR.1943-5452.0001094

Meshram, S.G., V.P. Singh, E. Kahya, M. Sepehri, C. Meshram, M.A. Hasan, S. Islam, P.A. Duc, 2022. Assessing erosion prone areas in a watershed using interval rough-analytical hierarchy process (IR-AHP) and fuzzy logic (FL). Stoch Environ Res Risk Assess 36; 297–312. https://doi.org/10.1007/s00477-021-02134-6

Mitasova, H., J. Hofierka, M. Zlocha, L.R. Iverson, 1996. Modelling topographic potential for erosion and deposition using GIS, International Journal of Geographical Information Systems, 10(5); 629-641. 10.1080/02693799608902101

Moore, ID., G.J. Burch, 1986. Physical basis of the length-slope factor in the universal soil Loss equation. Soil Science Soc Am J., 50; 1294-1298.

Nelson, T., D. Mazurek, A. Ruesch, S. Kempen, D. Evans, 2014. Erosion Vulnerability Assessment for Agricultural Lands (EVAAL) Methods Documentation, Wisconsin DNR. http://dnr.wi.gov/topic/Nonpoint/documents/EVAAL/EVAAL_Methods_v1_0.pdf

Pal. S., 2016. Identification of soil erosion vulnerable areas in Chandrabhaga river basin: a multi-criteria decision approach. Model. Earth Syst. Environ., 11 p.

Patel, A., K.V. Ramana Rao, Y.A. Rajwade, C.K. Saxena, K. Singh, A. Srivastava, 2023. Comparative Analysis of MCDA Techniques for Identifying Erosion-Prone Areas in the Burhanpur Watershed in Central India for the Purposes of Sustainable Watershed Management. Water, 15; 3891. https://doi.org/10.3390/w15223891

Pavelsky, T.M., L.C. Smit, 2008. A software tool for the calculation of river widths from remotely sensed imagery. IEEE Geosci Remote Sens Lett., 5(1); 70–73.

Pourkarimi, M., S. Mahmoudi, M. Masihabadi, E. Pazira, A. Moeini, 2018. Possibility of using land components for estimation of soil erosion: A case study of a watershed of the second urban phase, Mashhad, Khorasan Province. Agriculture & Forestry, Vol. 64 Issue 2; 147-161, Podgorica. DOI: 10.17707/AgricultForest.64.2.11

Rahmati, O., N. Tahmasebipour, A. Haghizadeh, H.R. Pourghasemi, B. Feizizadeh, 2017. Evaluating the infuence of geo-environmental factors on gully erosion in a semi-arid region of Iran: an integrated framework. Sci Total Environ, 579; 913-927.

Refahi, H., 2009. Water erosion and its control. Tehran Publications. Tehran. 315 p.

Ren, L., J. Huang, Q. Huang, Y. Liang, 2018. A fractal and entropy-based model for selecting the optimum spatial scale of soil erosion. Arab J Geosci 11(8); 161-176.

Rezaei, J., 2016. Best-worst multi-criteria decision-making method: Some properties and a linear model, Omega, 64; 126-130.

Saaty, T.L., 1977. Scaling Method for Priorities in Hierarchic Strictures, Journal of Mathematical Psychology. Vol. 15, pp. 234-281.

Saaty, T.L., 1999. Fundamentals of the analytic network process. International Symposium on the Analytic Hierarchy Process, Kobe.

Sadoddin, A., V.B. Sheikh, R. Mostafazadeh, M. Halili, 2010. Analysis of vegetation-based management scenarios using MCDM in the Ramian Watershed, Iran. International Journal of Plan Production. 4(1); 51-62.

Safari, A., M. Ahmadi, S. Rahimi Har abadi, 2015. Gully erosion zonation by ANP and AHP models in Kahor watershed, Fars province, Journal of Earth Science Researches, 24; 94–110.

Schwab, G.O., D.D. Fangmeper, W.J. Elliot, R.K. Frevert, 1993. Soil and Water Conservation Engineering, P, 9-113.

Singh, G., R.K. Panda, 2017. Grid-cell based assessment of soil erosion potential for identification of critical erosion prone areas using USLE, GIS and remote sensing: A case study in the Kapgari watershed, India, International Soil and Water Conservation Research, Volume 5, Issue 3, Pages 202-211, ISSN 2095-6339, https://doi.org/10.1016/j.iswcr.2017.05.006.

Soyoung, P., C. Jin, S. Jeon, H. Jung, C. Choi, 2011. Soil Erosion Risk in Korean Watersheds, Assessed Using the Revised Universal Soil Loss Equation, Journal of Hydrology, 399 pp.

Taha, Z., S. Rostam, 2012. A hybrid fuzzy AHP-PROMETHEE decision support system for machine tool selection in flexible manufacturing cell. J Intell Manuf, 23(2012); 2137–2149

Triantaphyllou, E., 2000. Multi-Criteria Decision Making Methods. In: Multi-criteria Decision Making Methods: A Comparative Study. Applied Optimization, vol 44. Springer, Boston, MA. https://doi.org/10.1007/978-1-4757-3157-6_2.

Tucker, G.E., R.L., Bras, 1998. Hillslope Processes, Drainage Density, and Landscape Morphology. Water Resour. Res. 34 (10); 2751–2764. Doi: 10.1029/98WR01474

Wentworth, C.K., 1930. A simplified method of determining the average slope of land surface. Am J Sci., 117; 184-194.