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Estimation of soil erosion using SLEMSA model and OWA approach in Lorestan Province (Iran)

S. Heydarnejad[1], A. Ranjbar Fordoei[*2], S.H. Mousavi[3], R. Mirzaei[4]

[1]Ph.D. in Combating Desertification, Department of Desert Science, Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran

[2]Associate Professor, Department of Desert Science, Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran

[3]Assistant Professor, Department of Geography and Ecotourism, Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran

[4]Assistant Professor, Department of Environmental Science, Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran

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Abstract

Identifying suitable models for estimating soil erosion is one of the most important issues facing decision makers and managers in comprehensive planning and management of soil and water. In this research, with the purpose of estimating soil erosion in Lorestan Province, the conventional SLEMSA method was jointly used with OWA (ordered weighted averaging) multi-criteria evaluation method. The results showed that in the SLEMSA model, erosion classes with very low and very high erosion rates with an area of 16334 and 167 km^2, covered the largest (58.7%) and the smallest areas of the region (0.6%), respectively. In the OWA method, on average, 63.67% of the area covering 18007 km^2 was located in a very low erosion class, while the very high erosion class with an area of 956.5 km^2, comprised 5.85% of the study area. The results of this research showed that besides using the SLEMSA model, the OWA method introducing a decision environment with risk and uncertainties can be used to estimate erosion, and its output can lead to a relatively precise assessment of the soil erosion in a short time and at a low cost for a vast area like Lorestan Province.

Keywords: Soil erosion, Erodibility, Topography, Vegetation, Ordered weight.

[*]Corresponding author; aranjbar@kashanu.ac.ir

Introduction

Soil erosion is a serious threat to the environment, health, and well-being of humans and one of the most important environmental challenges in the world. The global cost of erosion is estimated at about $ 400 million per year. In Iran, soil degradation and water erosion are among the main factors threatening the sustainability of resources and sustainable development, such that, about 36% of agricultural land and 60% of Iran's total soils are at risk of erosion. Estimates indicate that the average erosion in Iran is 30 to 35 tons per hectare per year, which is 4.3 times the global average (FAO, 1948). In recent years, the rate of erosion has changed in different parts of Iran. One of the areas where soil erosion has caused environmental concerns in recent years is Lorestan Province. In some parts of the province, the erosion rate is more than 25 tons per hectare per year which is more than twice the allowed erosion rate (Bennett 1939). However, researchers have identified various other factors that contribute to soil erosion such as geographic location, climate, natural and terrestrial properties as well as human factors such as deforestation, overgrazing, land use change, and inappropriate agricultural practices (Momeni, 2010).

Identifying vulnerable ecosystems and understanding the extent to which these ecosystems are destroyed is an integral part of the principles of good planning and management. Therefore, awareness of the risk of soil erosion and identification of critical areas has become one of the priorities of management and conservation plans of local authorities in Iran. To address this concern, the authorities face two major problems: the lack of precise statistics and shortage of available data in the province on the extent of erosion, and the variety of scientific methods of estimating erosion, which may lead to greater confusion, as well as improper management prioritization and wrong decisions. However, officials and executives are always looking for definitive and executive responses, which is not easy. One of the most useful decision support tools is the multi-criteria decision-making method that tries to facilitate the decision-making process and reduce the risk of wrong decisions. Multi-criteria decision-making analysis (MCDM) has been started since the early 1960s. This method includes a set of options that are evaluated based on possible inconsistencies. GIS-based multi-criteria decision-making can combine spatial data according to the type of decision-making method (Rinner and Malczewski, 2002). One of the most suitable multi-criteria evaluation methods is ordered weighted averaging method (OWA), which, by considering the evaluation risk in decision-making, helps decision-maker in different decision-making situations in order to make better decisions with a lower risk of mistakes (Yager, 1988; Calijuri, 2004; Makropoulos and Butler, 2005). In this method, in addition to the weights related to the relative importance of the criteria, ordinal weights are also used (Yager, 1988). By changing the weight of each factor, we can produce a wide range of output maps (Boroushaki and Malczewski, 2008). The OWA approach has been used in many cases, such as land-use suitability and residential quality assessments (Boroushaki and Malczewski, 2008), landslide hazard map (Gorsevski, 2012), fuzzification of linguistic quantities in residential development (Malczewski and Rinner, 2005), and selection of landfill (Gemitzi et al., 2007), but so far, no study has been conducted on the use of the OWA method to estimate erosion in the area of study.

In addition to multi-criteria assessment methods, there are traditionally several methods for estimating and measuring erosion. These methods range from simple models that include a statistical relationship to hybrid equations that are related to the physics of components or the mechanism of erosion process (Rompaey and Govers, 2002). One of the empirical models of soil erosion estimation is the SLEMSA model, which simply estimates the erosion rates at different points using the least indicators and with the lowest cost, and it is used by integrating the data using GIS for assessment of the rate and distribution of soil erosion. This model can be very useful for a large area with a minimum available data. The SLEMSA model was first used by Elwell (1978) to assess the erosion rate in

Zimbabwe and showed acceptable results. This model has been widely used in Africa (Granger, 1984), especially in South Africa (Elwell and Stocking, 1982; Chakela et al., 1989; Smith et al., 1997; Svorin, 2003) and has shown acceptable results. The SLEMSA model has also been compared with other models such as USLE (Igwe et al., 1999; Breetzke et al., 2013), which shows that while the SLEMSA model uses fewer indicators for estimating erosion but this model has better agreement with the region's conditions. In Iran, several studies have also been carried out using the SLEMSA model, which shows that the computational results of this model are in accordance with the conditions of the region (Pourmohamadi Amlashi, 2001; Entezari Najaf- Abadi and Gholami, 2013; Salari, 2013; Taghavi and Hashemi, 2013; Mousavi, 2017).

Based on the premises, the objectives of this research were set as follows: 1. Estimation of soil erosion in Lorestan Province using the SLEMSA model as a simple and widely used method, and 2. Incorporation of the OWA decision-making method to include risk in erosion estimation and mapping.

Materials and Methods

Study area

Lorestan Province with an area of 28,329 square kilometers is located between 46 degrees and 51 minutes' eastern longitude and 32 degrees and 37 minutes to 34 minutes' northern latitudes (Figure 1). Oshtorankuh with a height of 4150 meters is the highest point of the province. Its lowest point lies in the south of the province and is about 500 meters above sea level. The climate is semi-arid and the maximum and minimum temperatures in the province are 47.4 and 35-, respectively.

Apart from the northern boundary of the province, which is mostly covered by agricultural lands and pastures, other areas are mostly oak forests (Figure 1). Major soils of Lorestan Province are categorized into two important categories of Entisols and Inceptisols, based on a comprehensive classification of soils. Entisols are mostly found in mountainous areas and hills of the province and the inceptisols in the plains and agricultural lands. Inceptisols are more developed than Entisols and have pronounced calcic, cambic, and ochric horizons. Mollisols and Vertisols categories have also been identified locally and scattered in the province. The soils of the province have mostly medium to heavy texture, with the acidity of 7.5 to 8.2 and salinity of less than 4 m mho/cm. These soils generally belong to the calcareous soils, which have significant amounts of lime on the surface and bottom horizons. (Lorestan Agricultural and Natural Resources Research Center).

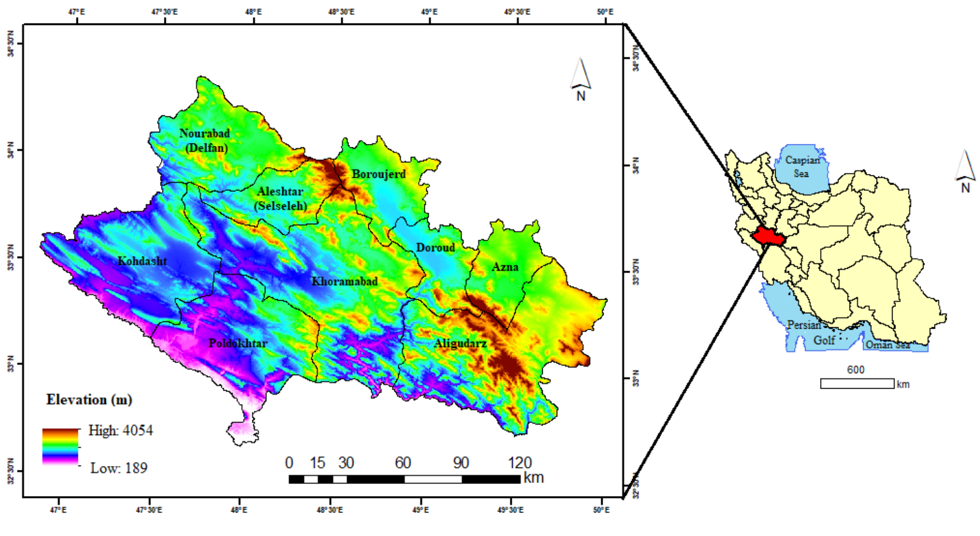

Figure 1. Location of the study area.

Erosion estimation

Figure 2 illustrates the implementation stages of the research. The SLEMSA model includes topographic indices (including slope length and gradient), climatic factors (kinetic energy due to falling drops of rain), vegetation (protective role of plants) and soil characteristics (soil erodibility) (Figure 2). The layers required for erosion zoning map of the study area were prepared in ArcGIS software. In short, a digital elevation map (DEM) was prepared with 30-meter cell size (prepared by the American Geological Survey) (Table 1). Then the slope length and gradient layers were plotted using this map (Figure 2). The soil classification map (prepared by the Natural Resources Office of Lorestan Province) (Table 1) was used to prepare soil erodibility layer. To calculate the vegetation factor, the land use map was prepared from the Natural Resources Office of Lorestan Province (Table 1) (Figure 2). Eventually, the digital layers of the effective indexes were combined with the SLEMSA model and the soil erosion map of the study area was prepared (Figure 2). We used the analytical hierarchy process (AHP) to determine the weight of the criteria and then the OWA method was used to calculate the ordinal weights of the criteria. Then, using quantifier-guided OWA, the weights were processed and the criterion maps were standardized and the soil erosion map of the study area was prepared (Figure 2).

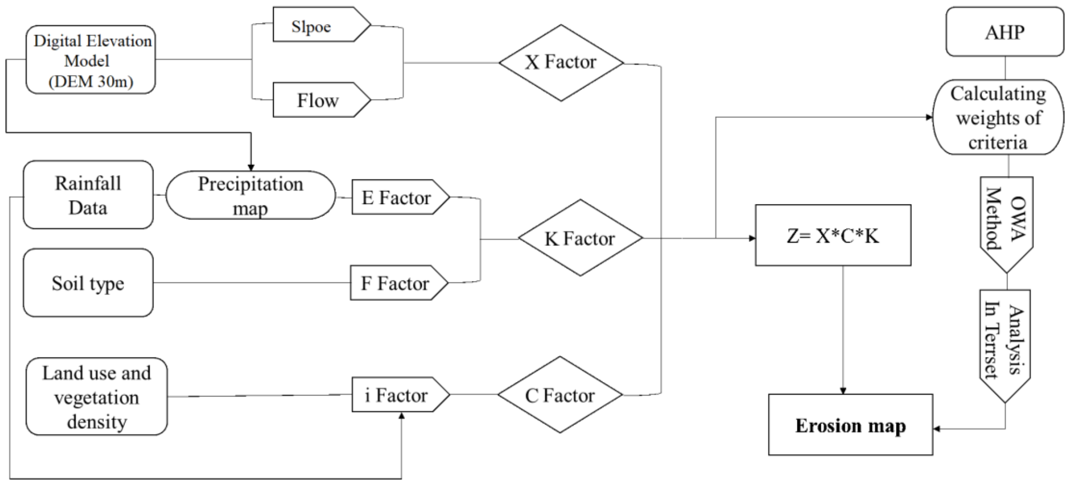

Figure 2. Flowchart of the implementation stages of the research in this paper.

Table 1. Description of data used in the study.

Sl. No.	Extracted parameters	Data type	Year	source
1	Rainfall	Monthly rainfall	2000-2015	Iran Meteorological Organization
2	Land use and vegetation density	Land use map	2010	Natural Resources Department (Lorestan Province)
3	Soil type	Soil map	2010	Natural Resources Department (Lorestan Province)
4	Slope and Flow	Digital elevation model (DEM 30 m)	2010	http://earthexplorer.usgs.gov/
5	Erosion	Daily Sediment	2000- 2010	Regional Water Organization (Lorestan Province)

SLEMSA method

As indicated, the SLEMSA model combines three variables of the topographic factor (X), soil loss due to the soil erodibility (K) and soil loss at the bare surface (C). The calculation of erosion in this model is carried out through equation 1 (Elwell, 1978):

$$Z= K.C.X \quad (1)$$

In this equation, Z is the estimated amount of soil loss in ton per hectare per year.

Topographic factor (X)

To determine the topographic factor variable (X) representing the elevation and shape of the ground, the slope map of the region was prepared in the ArcGIS software environment through a digital elevation model. The slope length was also obtained using this model and the functions in this software.

Since there is correlation between the gradient and the length of the slopes, therefore, the topographic factor is calculated from equation 2.

$$X=L0.5(0.76 + 0.535 + 0.0765S2)/25.65 \quad (2)$$

In this equation, L is the length of the slope and S is the gradient percentage of the study area (Elwell, 1978).

Erodibility factor (K)

To calculate this parameter, two factors of soil exhaustion (F) and kinetic energy of rain (E) were calculated as follows:

For the kinetic energy of the rain, considering the climatic features and rainfall regime of the study area, equation 3 was used:

$$E= 17.368\times P \quad (3)$$

In this equation, P is the average annual rainfall in millimeters (11).

Calculation of soil exhaustion (F)

Elwell method was used to calculate this variable. For this, F is calculated according to local conditions and soil type (Table 2).

Table 2. Method of assessing F value (from Contour Layout Design, Department of Conservation and Extension, Rhodesia).

Soil texture	Soil type	Basic index
Light	Sands, Loamy sands, Sandy Loams	4
Medium	Sandy clay Loam, Sandy clay	5
Heavy	Clay, Heavy clay	6

For soil erodibility map, the soil map of the area (extracted from data of the Natural Resources Office of Lorestan Province) was digitized and converted into raster. After calculating the values of F and E, the value of K was calculated from equation 4:

$$K=\exp\{(0.4661+0.7663f)\ \mathrm{Ln}\, E + 2.884\text{-}8F\} \quad (4)$$

In this equation, K is the amount of exhausted soil of the surface, E is the average kinetic energy of the rain (J / m^2), and F is the soil exhaustion (Elwell, 1978; Ramesht & Shahzeidi, 2011).

Vegetation factor (C)

To evaluate and measure the vegetation factor indicating the amount of soil loss at bare surfaces and the effect of vegetation on soil conservation, we first calculated the quantity of vegetation cover (i) using Table 3. After calculating the amount of i and placing it in the equations (5) and (6), the vegetation factor was obtained (Stocking et al., 1988).

Table 3. Cover values or mean seasonal interception of erosive rain (Stocking et al., 1998).

Grazing pressure	Cattle-days per hectare	Cover % or Mean Seasonal Interception, i, % (Rainfall zone) 600 mm	800 mm
Light	0-100	70	90
Moderate	100-300	40	60
Heavy	More than 300	20	30

C_1= exp (0.06i) when i<50% (5)

C_1= (2.3-0.01 i)/30 when i 50%≥i (6)

To estimate the amount of soil loss at bare surfaces and to demonstrate the effect of vegetation on soil conservation, the land use map was digitized based on the type of land-use and vegetation cover density. Then, vegetation factor values were calculated according to the condition of rangeland and rainfall in the area.

B. OWA method

Multi-criteria evaluation methods usually include a set of evaluation criteria in the form of maps and layers. But important issues in decision making are how to combine the criterion maps with a set of weights as well as decision makers' priorities. The multi-criteria evaluation includes a set of priorities as the standard weights:

For j=1, 2… n → wϵ [0, 1]

With map layers and standard weights, the combined OWA operator assigns the set of ordinal weights V = v_1, v_2... v_n to the cell i, so that for each j = 1, 2... n, we have:

vjϵ[0, 1] and $\sum_{j=1}^{n} v_j$

The combined OWA operator is defined as follows (Malczewski et al., 2004, Yager, 1988):

$$OWA_i = \sum_{j=1}^{n}\left(\frac{u_j v_j}{\sum_{j=1}^{n} u_j v_j}\right) z_{ij} \qquad (7)$$

According to equation 7, u_j is the jth criterion weight, V_j is the ordinal weight of the criterion j and z_{ij} is the ranked value of the jth criterion. Criterion weight is relative description of the importance of a particular criterion and ordinal weight comprises standard rating weights, j is the feature of criterion map and the ordinal weight is assigned to the feature ith position (Jiang and Steman, 2000).

Specifying the type of quantifier (Q)

Fuzzy quantifiers provide the possibility of converting linguistic expressions into mathematical terms and they are divided into absolute and relative quantifiers based on the type of expression. Expressions such as “minimum 4” and “about 5” are absolute quantifiers and expressions like “mostly” and “almost all” are relative quantifiers. These quantifiers are displayed as fuzzy sets at intervals [1 and 0] and used to measure the proportions of the set (0 and 1 are the proportion of 0% and 100%, respectively). It cannot be precisely stated which of the various types of quantifiers are more suitable for multi-criteria evaluation. In this study, the following relative quantifiers were selected from the regular incremental quantifiers (Table 4).

Table 4. Regular Incremental Quantifier Values.

Quantifiers language (Q)	At least one	Few	Some	Half	Many	Most	All
α	0.0001	0.2	0.5	1	2	10	1000

Calculation of ordinal weights

The ordinal weights control the method of combining the weighted criteria and are assigned to the location of the cells. In other words, these weights make it possible for the decision maker to interact with the same weight and importance of the criteria that are more important for him in decision making. Also, ordinal weights provide the possibility of controlling the risk and compensation level for the decision-maker.

The ordinal weights were calculated according to the standard weights obtained by the AHP method and the selected quantifiers (Table 4), and by using the following relation:

$$v_{ij} = (\sum_{j=1}^{n} u_j)^{\alpha} - (\sum_{j=1}^{n-1} u_j)^{\alpha} \quad (8)$$

In this equation, uj is the weight of the jth criterion.

For standardization, firstly, the raster layers of the criteria were standardized using the minimum and maximum values and with the help of linear membership function in Idrisi software environment (Figure 3). After standardization, the standard maps were prepared using the fuzzy logic membership functions and the mean ordinal weights in a scale of 0 to 255. (Eastman, 2003).

Results and Discussion

The results of the soil erosion in the study area are presented according to the effective factors in Figure 3. The gradient and length of the slope maps are presented in Figure 3-g. In this map, the highest value of topographic factor (0.47), are observed in the northeast, central, south, and south-east elevations, and the lowest topographic factors are found in the lower elevations and plains (Figure 3-g). These findings show that the gradient and slope length are heavily influenced by elevation and by increasing their values, the topographic factor, shows an increasing trend. The results of estimation of climatic erosion factor and soil erodibility (K) are presented in Figure 3-h. This factor was calculated according to equation (3) for the erodibility and kinetic energy of the rain maps. Based on these maps, most of the study area have K values of less than 0.01, due to low slope and deep and stable soil, in lowlands and plain areas, which are located in the northeast and eastern and the western half of the study area. In contrast, parts of the eastern, southeast, and northern regions (northern mountainous regions) of the study area have the highest values of K (0.31). These points have the highest rainfall, the highest slope, and unstable and undeveloped young soil with low thickness (Figure 3-h). Vegetation factor (C) was estimated based on the type of land-use and vegetation value (Table 3) using equations (5 and 6). Based on the results, the lowest amount of vegetation factor (C) is related to agricultural areas located in western parts and plains and lowlands of the northeast to the southeast borders. On the contrary, the maximum amount of vegetation factor (0.54) is observed in rangeland areas with thin and poor vegetation cover.

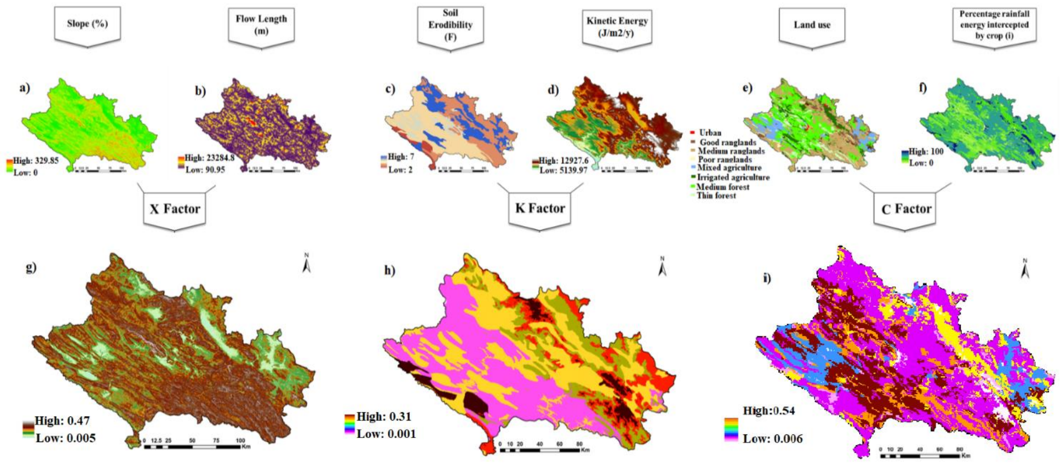

Figure 3. a) Slope, b) Flow Length, c) Soil Erodibility, d) Kinetic Energy, e) Land use, f) Percentage of rainfall intercepted by crop, g) X Factor, h) K Factor, and i) C Factor.

Vegetation factor (C) depends on the soil type, and vegetation percentage, and it is observed that in areas with thin and poor vegetation cover, the amount of this factor is minimum. It is generally concluded that the topographic factor is the most effective factor in erosion and the factors of erodibility and vegetation are in the next ranks. The results of this study are in line with the results of the study conducted by Entezari et al. (2012), Entezari and Gholami (2012), and Mousavi (2017) and shows that the topographical factor is the most effective factor in the erosion of the study area.

Estimating erosion with the SLEMSA model is presented in Figures 4 and 5. The results show that the range of erosion is from zero to 72.03 tons per hectare per year. Also, the results show that the very low erosion class has the largest area covering 16334 square kilometers (more than 80 percent), which is located in flat areas with the lowest elevation, low slope, and relatively deep soil. For this reason, these areas are stable with less erosion. After this class, there are low, medium, high, and very high erosion classes. The highest amount of erosion is found in mountainous areas with maximum gradient, but these areas are very small in size and cover only 167 km2 (about 4%) of the province (Table 5). According to SLEMSA model, topographic factor (slope) is the most effective factor in the erosion of the study area. However, areas with a high slope are small (about 4%), and in contrast, more than 80% of the province is located on very low and low erosion class in plain and flat areas. Considering the presence of deep soils and vegetation in these areas, we should not ignore the valuable and effective role of vegetation in controlling the erosion of the study area. Because topography and soil erodibility factors are among the inherent factors determining soil sensitivity to erosion and the vegetation is a human controlled factor, therefore, by implementing conservation measures and preserving existing vegetation, erosion risks can be reduced to a great extent.

The results of this study are in line with the study of Mohammadi et al. (2017), which was conducted using the CORINE, ICONA, USPED and RUSLE models in the Manderjan Watershed, as well as the study results of Entezari and Gholami (2012) in the Rumeshkan Basin, and Mousavi (2017) on the Miami Basin in Shahroud, and Entezari et al. (2012) in the Bardeskan Watershed. In these studies, it was revealed that there is a significant and direct relationship between the gradient of slope and the amount of soil erosion in the highlands and vice versa.

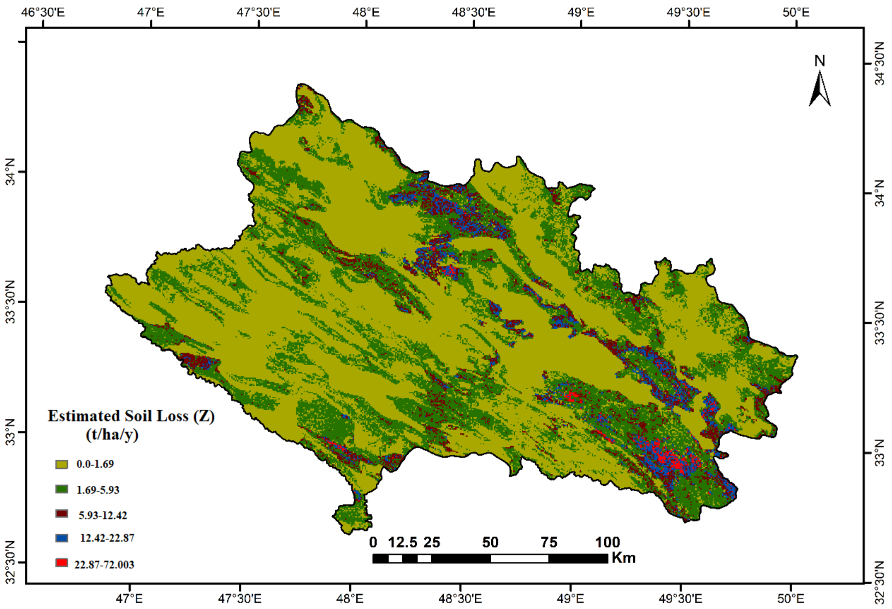

Figure 4. Soil Erosion Map by SLEMSA model.

Table 5. The status of the study area in terms of erosion (Z).

Erosion	Erosion class	Area (km^2)	Area (%)
0.0 - 1.69	Very Low	16334.5	58.69
1.69 - 5.93	Low	8684.5	31.20
5.93 – 12.42	Moderate	1802.5	6.47
12.42 – 22.87	High	844.25	3.03
22.87 – 72.003	Extreme	167	0.6

OWA method results

We used Expert Choice software, to obtain factors weights based on pairwise comparisons and expert opinions (15 experts participated in this study) (Table 6) and using the weight of criteria, ordinal weights were calculated (Table 7), and finally, based on these weights, erosion zoning maps were presented in Figure 4. The results of the pairwise comparison showed that among the criteria, vegetation and topographic criteria had the highest (0.6267) and lowest (0.936) weights, respectively.

Table 6. Pairwise comparison of criteria.

Factors	Topography	Erodibility	vegetation	weight
Topography	1	0.5	0.5	0.0936
Erodibility	2	1	0.2	0.2797
vegetation	2	5	1	0.6267

* Consistency Rate = 0.06%

Table 7. Ordinal weights.

	OR ness (α)						
	0.0001 OR (Max)	0.2	0.5	1 WLC	2	10	1000 AND (Min)
Factors	Order Weight						
Topography	1	0.021	0.053	0.093	0.108	0.0015	0
Erodibility	0	0.087	0.26	0.279	0.040	0.0012	0
vegetation	0	0.061	0.07	0.629	0.203	0.0005	0

The erosion map of the study area was prepared according to the OWA process in five classes including very low, moderate, high, and very high. Table 8 lists the extent of erosion classes based on seven scenarios. The scenarios of the OWA method were provided using the possibility of decision-making at risk and non-risk conditions and also compensating for the weights of other criteria. However, it is expected that in the zoning of the erosion map, this method, while preserving decision risk-taking, will not overlook the impact of the criteria. In the first scenario, 56.5% of the province was in the high erosion class and 63.48% in the low erosion class (Figure 5). This highlights the maximum level of risk and recoverability of this operator. In the second scenario, 65.1 percent of the province was located in the very low erosion class and 7.6 percent in the very high erosion class (Figure 5). In the third scenario, 66.86%, 5.56%, 14.59%, and 12.96% of the province were located in the very low, very high, moderate, and high erosion classes, respectively (Table 8). According to the fourth scenario, the highest (63.76%) and lowest (3.38%) area of the region fell in the low and very low erosion classes, respectively. Also, 15.29%, 11.69%, and 5.85% of the area were located in the moderate, high, and very high erosion classes, respectively (Figure 5). In the fifth scenario, the highest and lowest area of the region (61.66% and 3.03% respectively) were located in very low and very high erosion classes (Table 8).

In the sixth scenario, which acts like the Boolean logic operator (OR), only very low and low erosion classes were detected. As can be seen, according to these operators, almost 84.97 and 15.01 percent of the total area of the province are located in the very low and low erosion classes, respectively (Figure 5). In the seventh scenario, which is based on AND logical operator, the risk level is minimal and irrecoverable. Accordingly, the whole area of the province is located in the very low erosion class (Table 8). Therefore, these scenarios are not suitable for determining vulnerable areas.

In the first, fourth, and fifth scenarios, as shown in the table, the study area is divided into five erosion classes from very low to very high. In the third scenario, about 60 percent of the province is located in the low vulnerability class. This scenario reflects the relatively high-risk situations. In the case of risk-taking, the fourth scenario is appropriate, in which the study area is located in five erosion classes from very low to very high (Table 8). According to the fourth scenario, the highest (63.76%) and lowest (3.38%) area of the region had low and very low erosion classes, respectively. Also, 15.29%, 11.69%, and 5.85% were located in the moderate, high, and very high erosion classes, respectively.

In general, the results of the OWA method indicated that the southeast, eastern, and northeastern mountainous regions, as well as parts of the western and southwest regions of the study area, had the highest degree of vulnerability to erosion, and the largest part of the region with the area of 18007 hectares falls in low erosion class. This can be due to the elevation and the land gradient. Determining the weight of different factors is one of the most important challenges in evaluation (Lee et al., 2009). Many researchers, including Saho et al., 2016; Nguyen et al., 2016; Lee et al., 2009; Wang et al., 2008 and Zhuang et al., 2007) have used AHP to weigh the criteria in their studies. In this research, we used AHP to weigh the factors. In the OWA method, the weight change of the indicators affects the prioritization of scenarios. So, attention should be paid to calculation and extraction of weights. In our study, the highest weight was given to vegetation factor, and as such, it had a significant impact on prioritizing scenarios, and the changes in this factor made the largest changes in the prioritization of scenarios.

Table 8. Erosion (Z) (km^2) in the study area based on seven scenarios of OWA.

OWA Scenarios	Very low		Low		Moderate		High		Extreme	
	Area	%	Area	%	Area	%	Area	%	Area	%
First scenario	956.5	3.38	179929.05	63.48	4121.71	14.59	3660.37	12.96	1572.53	5.56
Second scenario	17761.68	65.1	3315.92	12.15	4168.96	15.28	2037.1	7.46	-	-
Third scenario	-	-	18885.55	66.86	4121.71	14.59	3660.37	12.96	1572.53	5.56
Fourth scenario	956.5	3.38	18007.14	63.76	4319.67	15.29	3303.98	11.69	16.8652	5.85
Fifth scenario	16824.57	61.66	2425.07	8.88	4982.46	18.26	2224.37	8.15	827.177	3.03
Sixth scenario	23184.83	84.97	4098.81	15.01	-	-	-	-	-	-
Seventh scenario	27283.69 9	100	-	-	-	-	-	-	-	-

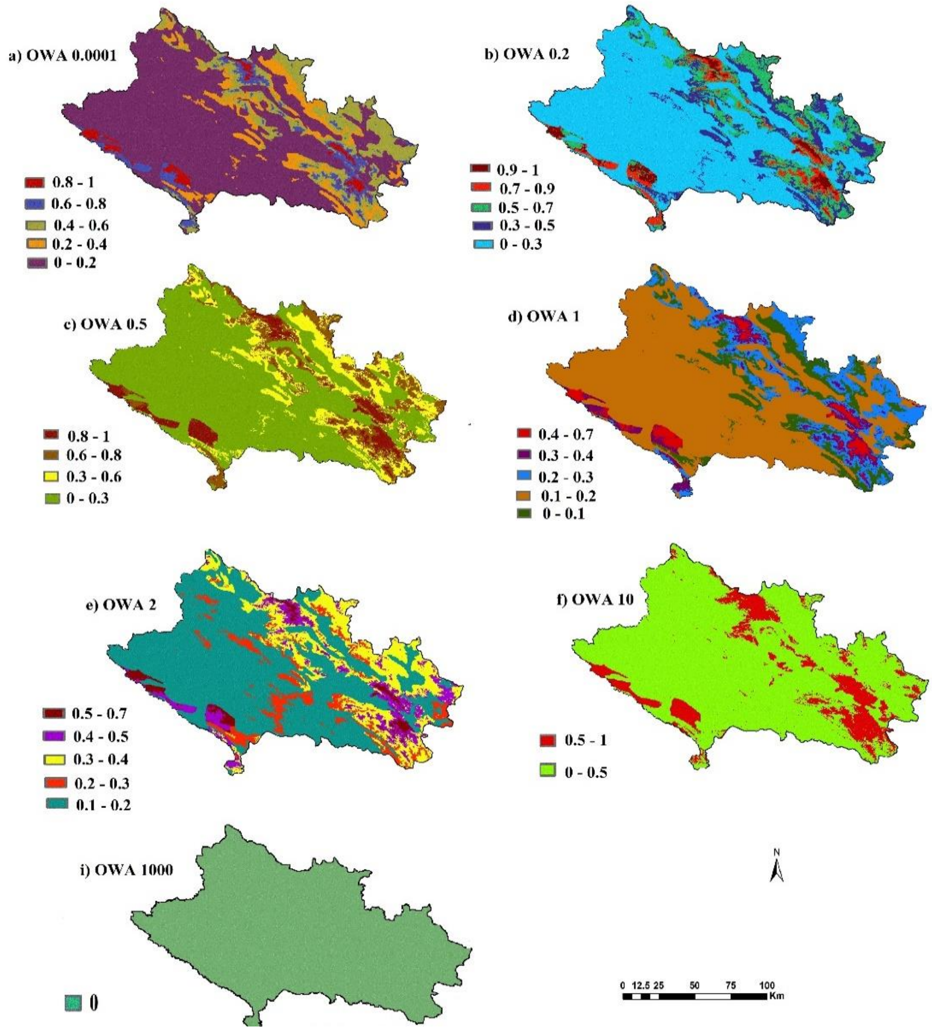

Figure 5. Soil erosion maps by ordered weighted averaging, a-i: The first to the seventh scenarios.

In general, it can be said that the studied area has low to moderate erodibility except for the high altitudes, with a very small area but high erosion rate. Therefore, with the management and controlling of the plains with low slope and deep soils and suitable vegetation, it is possible to counteract the development of erosion in these areas.

Conclusions

The lack of knowledge about the use of simple methods or models for estimating the rate of erosion with minimum available data, is one of the most important problems that officials in Iran and especially in Lorestan Province have not paid much attention to. The experimental model of SLEMSA is one of these models. In this research, with the purpose of estimating the soil erosion rate of Lorestan Province, this model was used along with OWA method. We see that despite the easy application of the SLEMSA model, the considered factors do not have prioritization, and the effect of each factor is considered the same. However, the OWA method can be used to prioritize factors affecting erosion. The combined application of the OWA and SLEMSA methods can lead to the elimination of SLEMSA model constraints and inclusion of the interdependence between different factors. The combined implementation of the two methods can lead to more accurate estimation of soil erosion in a short time and at a low cost for a large area such as Lorestan Province. As a result, high erosion areas can be well managed and controlled. In addition, in many cases, there is a risk associated with lack of accurate data which can be tackled by the OWA. As such, the final decision is influenced by the level of risk aversion and risk-taking of decision-maker. Therefore, using multi-criteria decision-making methods provide an optimal decision-making environment to determine optimal management options using different models.

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