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Using Multi–Criteria Evaluation (MCE): Analytical Hierarchy Process (AHP) In Investigation of Erosion Phenomenon in Arid Zones (Case Study: Watershed of Bechar, Southwest of Algeria)

Abdeldjalil BELKENDIL [1*], Mohammed HABI [1], Morsli BOUTKHIL [2], Omar BOUZOUINA [1], Samira BOUFELDJA [3]

[1] Laboratory 60: water resources valorization, Science and Technology Faculty, university of Tlemcen, Algeria.
algeria7002@gmail.com
[2] National forest research institute, EL Mansourah, *Tlemcen, Algeria*
[3] Laboratory 25: Water and soil resources. University of Tlemcen, Algeria

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Using Multi–Criteria Evaluation (MCE): Analytical Hierarchy Process (AHP) In Investigation of Erosion Phenomenon in Arid Zones (Case Study: Watershed of Bechar, Southwest of Algeria)

Abdeldjalil Belkendil, Mohammed Habi, Morsli Boutkhil, Omar Bouzouina, Samira Boufeldja

Utilisation de l'évaluation multicritères (MCE): processus de hiérarchie analytique (AHP) dans l'investigation du phénomène d'érosion dans les zones arides (étude de cas: bassin versant de Bechar)

L'érosion des sols est considérée comme un phénomène naturel qui menace la stabilité des sols, en particulier dans les régions arides, par deux agents importants, l'eau et le vent. Le bassin versant de Bechar est situé dans le sud-ouest de l'Algérie. Cette région est caractérisée par un régime climatique aride. L'objectif principal de cette étude est d'estimer le phénomène d'érosion des sols à l'aide de l'évaluation multicritères (EMC). L'équation de perte de sol universel (USLE) est utilisée pour générer les couches thématiques des facteurs de modèle qui sont érosivité (R), érodibilité (K), la couverture végétale (C), de la topographie (LS) et l'utilisation du sol (P), Les poids relatifs des facteurs définis sont déterminés en appliquant le processus de hiérarchie analytique (AHP) en raison de sa robustesse d'extraire les poids d'importance pour chaque facteur. La carte finale des risques d'érosion des sols du bassin versant de Bechar est développée. Sur la base de l'application de la méthode d'évaluation multicritères (EMC), Les données pour résultat montre que 9%(548.343 km2) du bassin versant est situé dans la zone de risque très élevé, 21% est dans la zone à risque élevé, 47% dans la zone à risque moyen et à 23 % dans la zone à faible risque de phénomène d'érosion des sols. Les résultats obtenus seront sans aucun doute aider les chercheurs à mieux caractériser le phénomène d'érosion dans la zone d'étude, puis de transférer les informations aux responsables afin d'intervenir dans le but de réduire l'aggravation de ce phénomène.

Mots-clés : processus d'analyse hiérarchique (AHP), évaluation multicritères (EMC), Erosion du sol, gestion du bassin versant.

Using Multi–Criteria Evaluation (MCE): Analytical Hierarchy Process (Ahp) In Investigation of Erosion Phenomenon In Arid Zones (Case Study: Watershed Of Bechar)

Soil erosion is estimated as a natural phenomenon which threats the soil stability especially in the arid regions by two important agents which are water and wind. Bechar's watershed is located in the south-west of Algeria; this region is characterized by an arid climate regime. The main objective of this study is to estimate the soil erosion phenomenon in Bechar's watershed using the multi-criteria evaluation (MCE). The universal soil loss equation (USLE) is used to generate the thematic layers of the model factors which are erosivity (R) , erodibility (K) , vegetation cover (C) , topography (LS) and the land use (P) , The relative weights of defined factors are determined applying analytical hierarchy process (AHP) because of its robustness in extracting the importance weights for each factor. The final map of soil erosion hazard of Bechar's watershed is developed. Based on the application of multi-criteria evaluation (MCE) method, the resulted data shows that 9 % of Bechar's watershed is located in very high risk zone, 21 % is in high risk zone, 47% in the medium risk zone and 23 % in the low risk zone of soil erosion phenomenon. The obtained results will undoubtedly help the researchers to better characterize the erosion phenomenon in the study area, and then transfer the information to the managers and the decision-makers in order to intervene for the purpose of reducing the aggravation of this phenomenon.

Keywords: Analytic hierarchy process model (AHP), Multi Criteria Analysis (MCE), soil Erosion, watershed management

1. INTRODUCTION

Soil erosion is estimated as a natural phenomenon which threats the soil stability, especially in the arid regions by two important agents which are water and wind (Abdi et al, 2013). Soil erosion is estimated as a complex problem by numerous factors such as rainfall intensity, soil types, vegetal cover and others parameters are the controllers of the intensity of water soil erosion (Ganasri et al, 2016). The main consequences of this phenomenon are soil loss, reduce water quality and increase the flood risk (Sakinatu et al, 2017), which makes the phenomenon of soil erosion among the most serious environmental problems at the global level (Paolo et al, 2016). Also, it has been classified by the Algerian Ministry of Water Resources as the first factor threatening water bodies and water stocks in dams (Jacobs et al, 2016).

For the objective to well understand the impact of phenomenon to facilitate the mission for the decision makers to well intervene by taking the appropriate solutions to reduce the negative effects of erosion on agriculture, infrastructure, water quality, etc (Abdi et al, 2013), assessment maps are essential tools to distinguish the most vulnerable zones by the soil erosion (Prasannakumar et al,2012) and the magnitude of each zone by using geographic information system GIS and numerical models which contributes to minimize the time and the efforts to generate the soil erosion hazards maps (Rahman et al, 2009). Many research papers have been conducted on this subject of soil erosion characterization to determine the zones the most touched by this phenomenon in order to be at the top of priorities for conservation (Biswas et al, 2015; Vulević et al, 2015; Micheli et al, 2013). Molla et al, 2017 classified the study watershed into conservation areas according to the type of conservation by three types: local topographic variation, agricultural productivity and land-use plans.

The main objective of this paper is to estimate the soil erosion phenomenon in Bechar's watershed using the universal soil loss equation (USLE) method combined by the methods of multi-criteria decision analysis (MCDA): analytical hierarchy process (AHP) (Jhariya et al, 2018; Arturo et al, 2017) to calculate the weightage of different factors of erosion phenomenon, The advantage AHP is its ability to deal with complex problems and provide more accurate solutions with the possibility of clarifying the importance of each variable from the rest of the other variables included in the study (Lee, 2010; Kirti , 2007). The obtained results will be used to determine the most vulnerable zones to soil erosion phenomenon to be as a priority in the conservation process.

2. METHODOLOGY

2.1 Study area

Bechar is located in the Southwest of Algeria (Figure 1)., characterized by an arid to semi-arid climate regime, with an area of about 162,200 km² and variable topographic features (MICL, 2011). The mean annual precipitation ranges from < 40 mm to more than 100 mm in the north-eastern part of the region. The temperature is also variable; it may rise to 50 °C in summer and drops to 7°C in winter (Boufeldja, 2014). The main source of water reserve in the region comes from the precipitation. Groundwater is considered as one of the most precious source for the survival of human kind to satisfy the fundamental necessities of life (Belkendil et al, 2018). The land cover in the watershed varies between three classes (forest, urban land and bare land). More than 92 % of the studied watershed consists of bare land (Figure 2). A small part of the watershed (272.64 km²) is estimated as forest zone where the impact of the erosion phenomenon is at its lowest level.

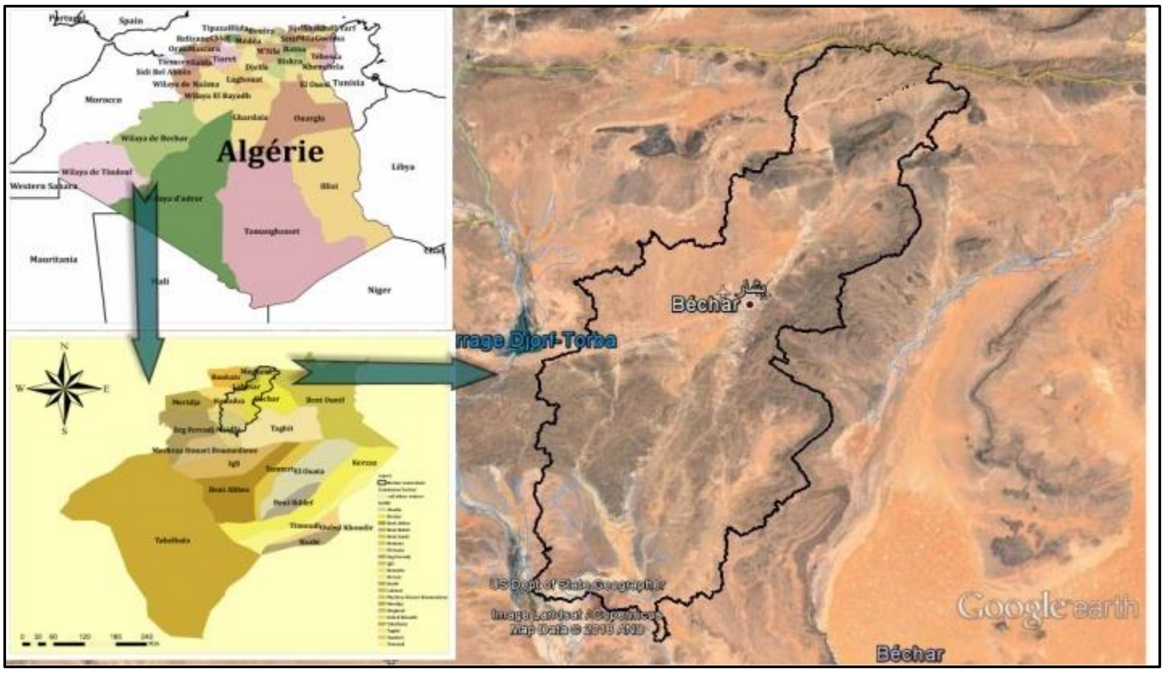

Figure 1. The geographical location of Bechar's watershed using Google earth satellite images.

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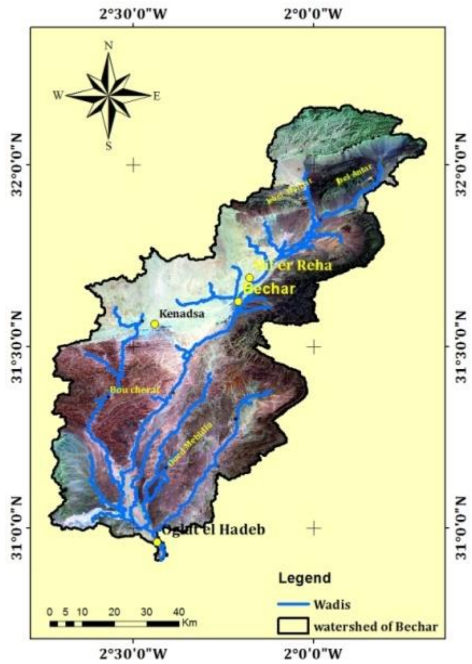

Figure 2. Landsat image of land cover and hydrographical network of Bechar's watershed

2.2. Universal soil loss equation (USLE)

The Universal soil loss equation (USLE) is an empirical model, was developed to quantify the soil erosion rate by sheet and rill erosion (Wischmeier, W.H. and Smith, D.D, 1978). USLE is designed to estimate the average of soil losses and soil particles dislocation and removal capability (ZISU et al, 2015). The rate of long-term annual average erosion (A) is computed using five factors as follows (Wischmeier and Smith, D.D, 1978):

$$A = R.\ K.\ LS.\ C.\ P \qquad (1)$$

Where (A) is the annual erosion rate (t/ha/y); R is the erosivity factor of rainfall (Mj.mm/ha/h), K is the soil erodibility factor; L is a factor of the slope length, S is the factor of slope stiffness; C is the vegetation cover factor and the P is support practices factor for soil conservation.

2.2. a. Erosivity Factor (R)

The rainfall erosivity factor (R) (Figure 3.a), is calculated as the product of the kinetic energy of storm events and intensity of maximum 30 minutes storms (Belkendil et al, 2016). To calculate this factor and because of gaps in rainfall data of the studied region, we used the regression of Arnoldus (1977) which it has been developed in Morocco $R = 0.264\ F^{1.50}$ (Hui et al, 2010), where (F) is the modified Fournier index to solve the problem involved in the distribution of monthly precipitation during the year where (Arnoldus, 1980):

$$F = \sum_{i=1}^{12} \frac{r_i^2}{P} \quad (2)$$

Where ri is the monthly precipitation and P is the annual precipitation.

2.2. b. Soil Erodibility Factor (K)

Soil erodibility factor (K) (Figure 3.b) is the susceptibility of soil to erosion, sediment transportability under standard conditions. The pilot plot is 72.6 feet long with a slope of 9%, this parcel is fallow and in continuous rows (Weesies et al, 1998). It depends on the physical and chemical properties of the soil, such as texture, aggregate stability, shear strength, the infiltration capacity, organic matter content, etc. (Nisar et al, 2000). In our study, we used an experimental relationship resulting by the test on (225) soil type linked by the geometric mean particle diameter of soil, the relationship is expressed as follows (Romkens et al, 2001):

$$K = 7.594\left\{0.0034 + 0.0405\, exp\left[-\frac{1}{2}\left[\frac{\log(D_g) + 1.659}{0.7101}\right]^2\right]\right\} \quad (3)$$

Where

$$D_g(mm) = \exp(0.01 \sum f_i \ln(m_i)\, with r^2 = 0.983 \quad (4)$$

Where

Dg: Geometric mean particle diameter.

Dg is the fraction of primary particle size in %, and *mi* is the arithmetic mean of the particle size limits of this dimension (Shirazi et al, 1984).

2.2. c. Topographic Factor (LS)

The effect of topography on soil erosion is taken into account by the LS factor in USLE (Figure 3.d), which combines the effects of slope length factor (L) and the slope steepness factor (S). Wischmeier and Smith (1978) defines the slope of length as the distance between the origin point of surface flow at the point where the slope decreases enough that the deposition starts or the point where the flow is concentrated in a defined channel. The stiffness of the slope reflects the influence of the slope on soil erosion (Wischmeier et al, 1965). Moore and Wilson (1992) proposed a modification for the original equation of LS factor of Wischmeier and Smith, 1978, the modified equation is:

LS = [flow acc* cell size /22.13] $^{0.4}$ * [(sin (slope*3.14 / 180)) / 0.0896] $^{1.3}$ (5)

2.2. d. Vegetation Cover Factor (C)

The cover management factor is one of the most important parameters of the Universal Soil Loss Equation (USLE) (Weiwei et al, 2011), it measures the combined effect of all related covers between them and the management variables; the C factor will be between 1 and close to 0 when C = 1 which means no effect of cover and the soil loss is comparable to that of a bare tilled fallow (Karaburun et al, 2010), when C = 0, that means a very high coverage effect resulting in no erosion. The creation of the C factor map (Figure 3.e) requires the existence of Landsat satellite images of high resolution, then we use the unsupervised classification of satellite images using ArcGIS software by classifying the image on 3 classes (bare soil, meager vegetation, Urban area,) giving a specific value for each class (Table 1, Jung et al, 2004).

Table 1. C factor values for land cover classes (Jung et al, 2004)

Land cover	C Factor
Urban area	0.1
Bare land	0.35
Dense Forest	0.001
Sparse Forest	0.01
Mixed forest and cropland	0.1
Cropland	0.5
Paddy Field	0.1
Dense grassland	0.08
Sparse grassland	0.2
Mixed grassland and cropland	0.25
Wetland	0.05
Water body	0.01

2.2. e. Support Practice Factor (P)

Practice support (P) is very important factor in the USLE model for soil loss estimation in the contaminated land and construction of the sites of erosion reclamation because this factor represents practices aimed at reducing erosion. The value of P in the USLE model is the ratio of soil loss with specific support practice for soil loss (Wawer et al, 2016).

In our study, P factor map (Figure 3.d) is created by estimation of different cultivated lands in the study area which is composed of contour, cropping and terrace lands, (Shin, 1999) proposed the P values according to the types of cultivation and slopes (Table 2, Table 3), P values range from 0 to 1, whereby the value 0 represents a very good support practice to resist against soil erosion and the value 1 represents no existence of support practice facility (Ashaq et al, 2011).

2.3. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is widely used statistical method and is estimated as a multi-criteria decision-making approach which was introduced by Saaty in (1980) (Saini et al, 2016). The researcher's interest in this method was due to the simplicity of mathematical characteristics, in particular, the ease accessibility of the required inputs. Another advantage of this method is the possibility of using it in several fields of scientific research and industrial applications with optimized judgments to take the best decision (Chakraborty et al, 2016). It is based on a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. A pair wise comparison is used to obtain the relevant data. The objective of using the comparisons is to extract the weights of used criterion depending on its degree of importance and relative performance for each decision criterion. A perfect consistency

Table.2. Support practice factor values according to the types of cultivation and slopes (shin, 1999)

Slope (%)	Contouring	Strip cropping	Terracing
0.0 -7.0	0.55	0.27	0.10
7.0 - 11.3	0.60	0.30	0.12
11.3 - 17.6	0.80	0.40	0.16
17.6 - 26.8	0.90	0.45	0.18
26.8 >	1.00	0.50	0.20

Table 3. Summary of USLE data preparation

USLE factor	Description	Data preparation
C factor	vegetation cover in the study area	Vegetation cover has been extracted from the Landsat images using the supervised classification
R factor	The influence of the rainfall	Calculated using the annual rainfall data of worldclim database (FAO source) , the Arnoldus regression has been used to calculate the erosivity value for each used meteorological station
LS factor	Topography influence	Calculated from Digital elevation model (DEM) using GIS
K factor	Soil type	Extracted from the Harmonized world soil data (HWSD) which is the production of the FAO database
P factor	Support practice	Classified from Digital elevation model (DEM) using GIS

is required to approve the comparisons (Rajeev et al, 2013). Currently, a lot of industrial applications rely on The Analytic Hierarchy Process (AHP) due to its effectiveness in obtaining a comprehensive decision based on a set of alternatives in terms of a number of criteria (Sorooshian et al, 2015).

Several studies in water quality characterization and environmental field have been conducted using Analytical Hierarchy Process (AHP) (Generino et al, 2014). In this paper, study has been done to enable diagnosis of the risk of soil erosion on the watershed of Bechar, as well as identify the places most vulnerable to erosion, with the results divided into classes and degree of importance of each class (Figure 4).

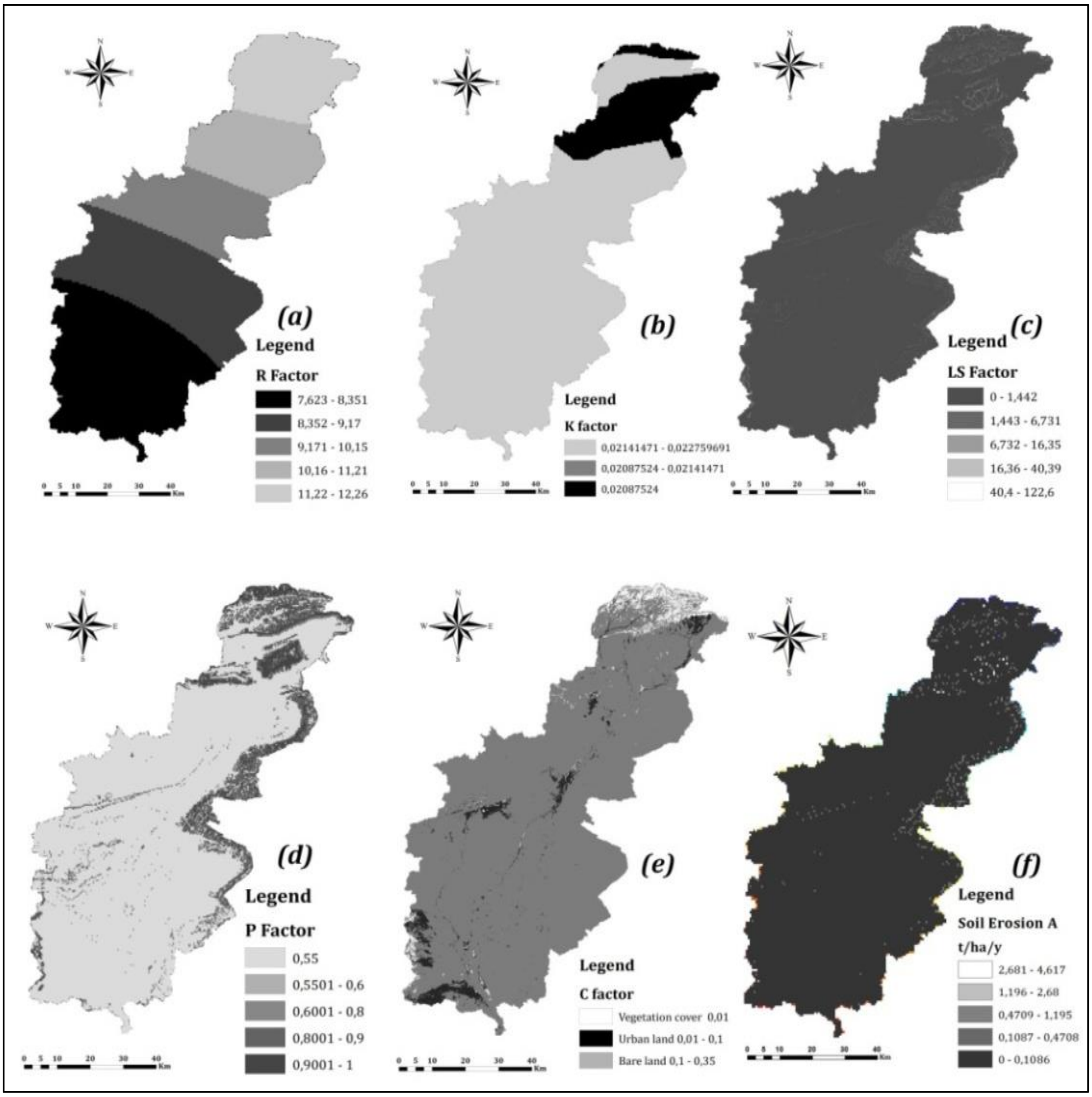

Figure 3: USLE factors maps and their sub-classes distribution
(a) Erosivity map (R) (b) Erodibility map (K) (c) LS factor map
(d) P factor map (e) C factor map (f) annual soil erosion map (A)

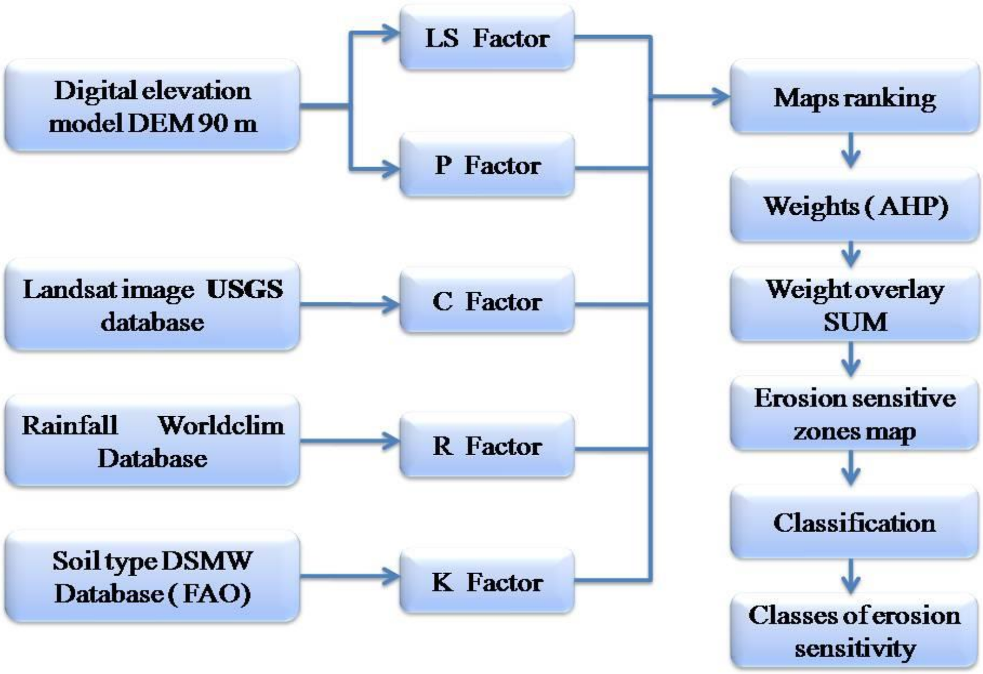

Figure 4. Methodology for the soil erosion assessment using USLE and AHP methods.

2.3. a. Determining the weights of the erosion factors

In the second step, for the preparation of Analytical Hierarchy Process model, weights were estimated for the factors based on the Saaty's recommended scale (Table 4) (Safian et al, 2011) for examination comprising of values ranging from 1 to 9 which portray the force of significance (preference/dominance).

Table 4. Recommended scale of comparison (Saaty)

Intensity of Importance	Description
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

2.3. b. Pairwise comparison matrix

Comparison matrix has to be prepared based on the Saaty's comparison scale (Table 4). Each factor obtains a value commensurate with its degree of importance as compared to other factors, the higher values in comparison scales were given to the factors of rain, land cover and slope because of its impact on the phenomenon of erosion (Demirel et al, 2011). In addition, the insertion of factors weights values in comparison scale is taking in consideration the positive and negative impact of each factor. For instance, areas with a dense vegetation cover contribute to reducing the risk of soil erosion despite the presence of high rainfall and slope. So, according on this analysis approach, the pairwise comparison matrix has been derived (Table 5). Number of comparisons could be found out by the formula given below (Mu et al, 2017):

$$comparisons\ numbers = \frac{n(n-1)}{2}$$

Where

n=Number of criteria

Table 5. Comparison matrix

Factors	R	K	C	LS	P
R	1	5	9	4	9
K	1/5	1	7	2	9
C	1/9	1/7	1	1/5	1/2
LS	1/4	1/2	5	1	4
P	1/9	1/9	2	1/4	1
SUM	1,67	6,75	24	7,45	23,5

2.3. c. Normalized pairwise comparison matrix

Each element of the matrix (Table 6) is divided by the sum of its column and the normalized relative weight factor is obtained (Vulević et al, 2015). The sum of each column is 1.

Table 6. Normalized matrix

Factors	R	K	C	LS	P
R	0,60	0,74	0,38	0,54	0,38
K	0,12	0,15	0,29	0,27	0,38
C	0,07	0,02	0,04	0,03	0,02
LS	0,15	0,07	0,21	0,13	0,17
P	0,07	0,02	0,08	0,03	0,04
SUM	1	1	1	1	1

Each criteria row wise is multiplied and to the power one Fifth (i.e. no. of criteria).Then each criteria is divided by the sum to find the weight factor (Table 7).

Table 7. Weighted normalized matrix

	$(R \times K \times C \times LS \times P)^{(1/5)}$	Weight factor
R	4,38	0,54
K	1,91	0,23
C	0,28	0,03
LS	1,20	0,15
P	0,36	0,04
SUM	8.13	1

2.3. d. Consistency ratio (CR):

Consistency ratio (CR) is used as a measure toot to evaluate the consistency of the experts judgments With regard to pairwise comparisons that they conducted based on their experience in the field. The consistency ratio is accepted if it is less than 0.10. (Rahman et al, 2009).

The Consistency Index CI of normalized matrix to determine how much inconsistency is in a matrix (Table 9) , and is calculated using the following formula i.e. $(\lambda_{max}-n)/(n-1)$, where n = number of criteria. The value of λ max is given by the following formula. The value of weight factor is shown in Table 8.

$$\boldsymbol{\lambda max} = (1.67\times0.54) + (6.75\times0.23) + (24 \times 0.03) + (7.45\times0.15) + (23.5\times0.04) = 5.45$$

Table 8: Random Indices for matrices of various sizes (Saaty and Vargas, 1991)

n	2	3	4	5	6	7	8	9	10
I	0.00	0.52	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 9. Values of CI and CR

CI= consistency Index , n=5	RI= random Consistency Index
$\boldsymbol{CI = \frac{\lambda_{max} - n}{n-1} = 0.11}$	$CR = \frac{CI}{RI}$= 0,099377

The resulted value of consistency index shows a high consistency ratio between the selected judgments because it falls below the threshold value which is 0.1, therefore the weights values can be accepted.

3. RESULTS AND DISCUSSION

According to the results obtained from USLE application process to determine the erosion phenomenon impacts on the watershed Bechar, we can see from the (Figure 3.a) the values of erosivity (R) vary between 7.62-12.26 MJ.mm .ha-1.h-1.year-1. It can be seen that the maximum value was recorded in the northern part of the watershed, with an average value of 9.33 MJ.mm.ha-1.h-1.yr-1. (Figure 3.b) represents the distribution of erodibility values (K) in the studied watershed; the minimum erodibility value is 0.020875 t. Ha. h ha^{-1}.MJ^{-1} .mm^{-1} was found in the southern part of the watershed, this part is characterized by a low slope and strong deposition of soil particles, the maximum value of erodibility 0.02276 t.ha.h.ha^{-1}.MJ^{-1} .mm^{-1} was recorded in the northern watershed where there is a concentration of a mountainous rock series.

Table 10. Distribution of erosion classes

SI No	Erosion class	Area (Sq.Km)	Area (%)
1	Low erosion	2 663,83	42,02
2	Medium Erosion	1 817,81	28,68
3	High Erosion	1 176,04	18,55
4	Very High Erosion	681,12	10,75

The result of applying equation (5) is shown in (Figure 3.c), according to this map, it can be distinguished that there is topographic difference along the watershed where the maximum values of LS are recorded in the north and north-west part of the watershed with a value of 122.6, the minimum value was recorded in the South of the watershed with a mean value equal to 0.23, which indicates a dominance of low slopes at the watershed level. Figure 3.d, characterizes the distribution map of P-factor values in the watershed, according to these results we can distinguish that the P values vary between 0.55 and 1. the procedure of classification of LANDSAT ETM + satellite images using the option '' supervised classification '' has produced a land use map of Bechar watershed. Figure 3.e illustrates that there are three classes of land use (vegetation cover, urban area and bare land), 3% of the watershed area is covered by a sparse vegetation cover generally concentrated in the northern part of the watershed. with a value of C equal to 0.01, the distribution of the urban area is limited in the central part of the watershed (City of Bechar and Kenadsa) with a value of C equal to 0.1, more than 92% of the surface of the watershed is without cover (bare land) with a value of C equal to 0.35. a thematic layer of each factor was produced and was incorporated into the equation (1) by means of raster calculator under Arcmap software, the (Figure 3.f) illustrates that the rate of loss in soil in the watershed Béchar reaches a maximum value equal to 4.61 t. ha^{-1}. yr^{-1} which was recorded in the mountain range of jebel antar and jebel Bechar, the average value of (A) which is equal to 0.016 t. ha^{-1}. yr^{-1}.

Depending on the use of AHP method, the resulted values of factors weights were calculated in percent 54%, 23%, 3%, 15% and 4% respectively for the erosivity factor (R), Erodibility factor (K) , vegetation cover factor (C), Topography factor (LS) and support practice (P). The resulted value of consistency ratio 0,099377 denotes accepted degree of consistency the pairwise comparison between these factors. The implication of GIS tools by the use of weighted sum overlay option in ArcGis 10.2, this process led to get a grid format map classified in four classes ranges between low erosion class and very high erosion class (figure 5). depending on this map, the low erosion class has the biggest extent on the watershed by 2663.83 km^2 which is localized mainly in the south part of the watershed, medium erosion by 1817.81 km^2, high erosion class by 1176.04 km^2 and the fourth class which is very high class by a 681.12 km^2 of the watershed surface (Table 10), this forth class is concentrated in the north part of watershed where are the mountainous hills such as Jebel Horreit and Jebel Antar (figure 5). These results show that the factors of the most influential impact in the soil erosion of the Bechar's watershed are the factors of topography (LS) as well as the amount of rainfall (R), so that the high degrees of slopes and rainfall amounts the watershed of Bechar are localized in the north and go down towards the outlet of the basin.

4. CONCLUSIONS

The model presented in this study illustrates the possibility of the use of the analytic hierarchy Process (AHP) method by using expertise to calculate soil erosion. Unlike other methods, that use sample data (e.g. USLE), the proposed method is based on expert's opinion to form the pair wise comparison taking in to consideration interdependence of the factors responsible for soil erosion. The methodology which has been followed in this work is based on the combination of real database of the phenomenon parameters, the parameters data such as (rainfall, erodibility, land cover, topography, and support practices) combined by the judgments of the experts in this environmental field. Application of the USLE model demonstrated that the annual erosion rate in the Bechar watershed ranged from 0 to 4.61 t. ha^{-1}. yr^{-1}, the maximum value is much more concentrated in the north and north-east of the basin, which is characterized by high rainfall, hilly topography and low ground cover. Belkendil et al, 2016, have made a similar study of the Guir watershed adjacent to the Bechar watershed, according to this study the annual erosion rate in the guir watershed ranged from 0 to 3.41 t. ha^{-1}. yr^{-1}.

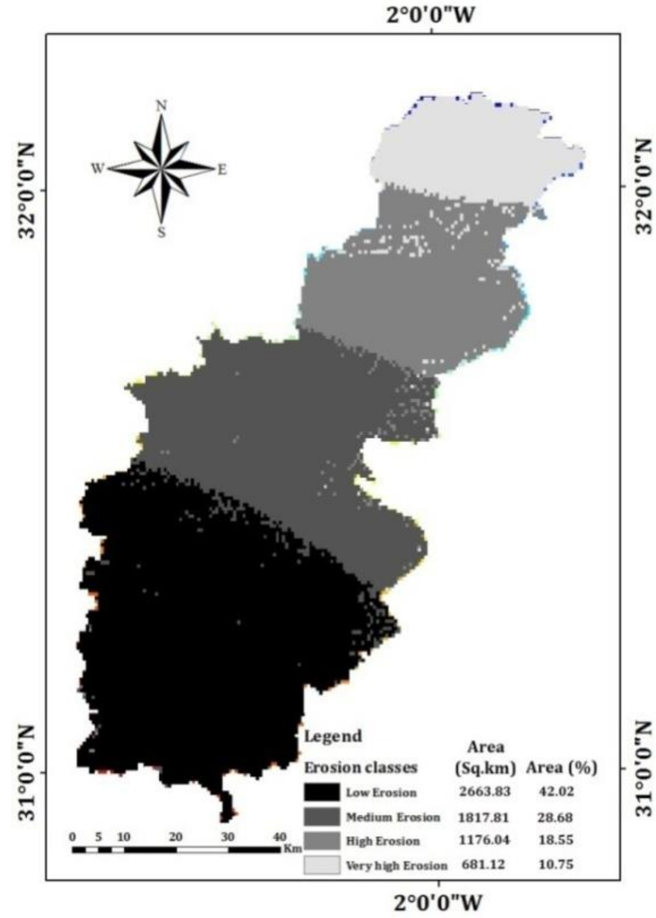

Figure 5. Spatial distribution of soil erosion classes

Moreover, by using the AHP and multi-criteria decision-making and GIS methods to optimize the criteria contributing to soil loss is unique in its approach.

Obtained results show that 10.75 per cent of total area of watershed is found under Very High risk of erosion. Around 18.75 per cent of watershed lies in high risk of erosion and 70 per cent of area shows medium to low risk of soil erosion which is concentrated in the lower part of the watershed. The model presented here is a universal model which can be applied in another local site by using soil erosion impact factors that depend on the study case conditions. The accuracy of the obtained results must also be discussed, Due to a number of reasons, perhaps the most important is the lack of similar studies in the neighboring zones of the study area in order to make a comparison of the obtained results in order to validate the values of annual erosion rate. However, these results will help the local environmental managers to take the necessary measures to conserve the soil in the region.

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