JOURNAL OF WATER AND LAND DEVELOPMENT

ISSN 1429–7426, e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Section of Land Reclamation and Environmental Engineering in Agriculture
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2020, No. 44 (I–III): 19–25
https://DOI.org/10.24425/jwld.2019.127041

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://journals.pan.pl/jwld

Received 27.01.2019
Reviewed 28.05.2019
Accepted 19.08.2019

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Spatialization of water erosion using analytic hierarchy process (AHP) method in the high valley of the Medjerda, eastern Algeria

Moufida BELLOULA, Hadda DRIDI, Mehdi KALLA

University of Batna 2, Department of Geography and Land Planning, No. 3 Constantine Street, Fesdis, Batna, Algeria;
e-mail: ✉ moufida.belloula@yahoo.fr; hadda.dridi@gmail.com; m_kalla1@yahoo.fr

For citation: Belloula M., Dridi H., Kalla M. 2020. Spatialization of water erosion using analytic hierarchy process (AHP) method in the high valley of the Medjerda, eastern Algeria. Journal of Water and Land Development. No. 44 (I–III) p. 19–25. DOI: 10.24425/jwld.2019.127041.

Abstract

The present study tries to quantify soil losses using Geographic Information Systems (GIS) and analytic hierarchy process (AHP) in the Medjerda watershed (Algerian-Tunisian border). The Analytic Hierarchy Process (AHP) method is used in the quantification of erosion qualitative characteristics, through its weighting. It is used for many problems requiring decision-making. This catchment area is characterized by moderately consistent lithology, irregular rainfall, medium slope and low vegetation cover, which makes it very sensitive to erosion. Therefore we claim to develop a spatialization map of vulnerable areas, based on analytic hierarchy process and GIS that define the combination of specific factors. The integration of the thematic maps of the various factors makes it possible to identify the impact of each factor in the erosion, to classify the sensitive zones, and to quantify the soil losses in the basin. This mapping will be an important tool for land use planning and risk management. From the distribution map of erosive hazards, we have identified four classes of vulnerability, areas with very high to high vulnerability are mainly in the northern part of the watershed (where the relief is very important).

Key words: *AHP, GIS, Medjerda River, spatialization, water erosion, watershed*

INTRODUCTION

Water erosion is a natural phenomenon that evolves along with human evolution and the severity of the climate. This phenomenon is defined as the process of detachment of soil particles by the effect of precipitation and runoff. In Algeria [SELMI, KHANCHOUL 2016], about 6 mln ha are exposed today to active erosion and on average 120 mln Mg of sediment are washed away annually by the waters. Annual losses of water in dams are estimated at about 20 mln m^3 due to siltation [BELARBI *et al.* 2018; REMINI 2000]. Estimating soil loss through erosion is difficult owing to the complex interaction of many factors such as climate, land cover, topography, and human activities [PAN, WEN 2014; LU *et al.* 2004].

In this respect, a qualitative modelling was chosen based on Analytic Hierarchy Process (AHP) combining the determinants of erosion and the most representative factors such as: lithologic factor, topographic factor, climatic factor as well as the land use [CHAKHAR, MOUSSEAU 2007]. This approach has been coupled with Geographic Information Systems (GIS) since these systems have high performance analysis, management and automation capabilities that are greatly useful for improving spatial multi-criteria decision-making [DROBNE, LISEC 2009; TEBBI *et al.* 2018].

The Medjerda catchment (Algerian-Tunisian border) is characterized by a moderate relief with medium slopes, a semi-arid climate, irregular rains, mostly stormy, poor vegetation cover and fragile soil. All these factors bring about strong erosion, whose consequences later on the Medjerda catchment. Quantification of transported sediments and mapping out of erosive risk areas is the purpose of this work.

MATERIAL AND STUDY METHODS

STUDY AREA

The Medjerda watershed is located in the North-East of the Algeria and is part of the eastern Saharan Atlas area on the Algerian-Tunisian borders. It is spread over an area of 7877 km^2 and a perimeter of 846 km. This catchment area is drained by two main tributaries: Oued Mellegue and Oued Medjerda that flow to the Algerian-Tunisian borders [BELLOULA 2008]. The watershed is located between the meridians of 7°37' E and 8°25' and the parallels 36°05' and 36°27' N (Fig. 1).

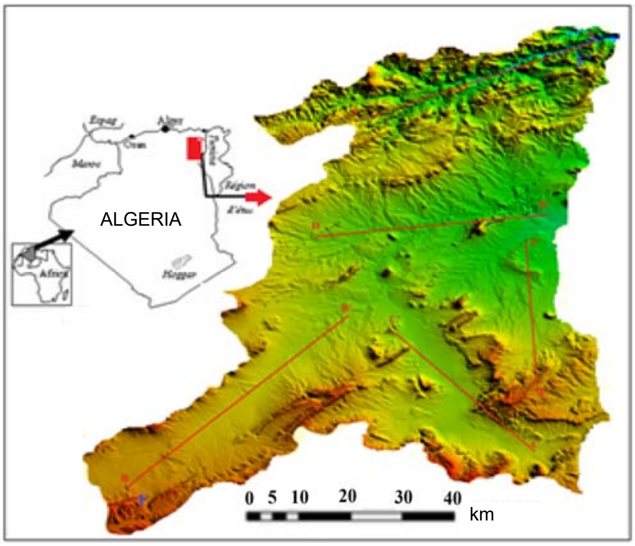

Fig. 1. Geographical map of the Medjerda catchment area; source: own elaboration

The Medjerda watershed is characterized by depressions (plains) filled by alluvial geological formations of medium to low permeability, surrounded by mountains composed of moderately permeable marly carbonate rocks. The altitude varied between 300 and 1700 m. Slopes lower than 8% occupy a large portion of the basin with 81%, while slopes greater than 15% occupy a percentage of 7%, the remaining lands corresponding to the slope between 8 and 15% with an area of 12%. The land cover of the study area includes agricultural and non-productive lands as well as forests occupying mainly the northern part (Souk Ahras) and the South (Tebessa) of the study area [BELLOULA 2008].

The watershed is characterized by a semi-arid climate with a cold winter and a dry and hot summer. The mean inter-annual precipitation recorded between 1970 and 2014 is estimated at 400 mm and the average temperature is 16°C, with deviations of 6 to 29°C and the average aridity index of De Martonne is 18.06.

METHODS – GENERAL DESCRIPTION

Water erosion of soil is a major process of degradation corresponding to the detachment and transport of particles under the combined action of rain and runoff. This phenomenon is widespread in different Mediterranean countries and especially in semi-arid areas [BOU KHEIR *et al.* 2001a]. This is explained by the fragility of the ecosystem and also by the disturbed relationship between the different natural factors [BENCHETRIT 1972]. To establish soil sensitivity map and assess the erosion conditions in the Medjerda watershed, we used a qualitative model based on a hierarchical multi-criteria analysis (AHP) combining the key factors of erosion. The AHP method is known in the category of CLP, it is developed by [SAATY 1977] and used in the quantification of qualitative characteristics, through its weighting [SAATY, VARGAS 1991; RAMOS *et al.* 2014; YALCIN *et al.* 2011]. It is used for many problems requiring decision-making, some have even pointed out that this method has revolutionized the way to solve complex problems [GRANDMONT 2013; SAATY, SODENKAMP 2010].

This method consists in determining the criteria to be taken into account according to the study. Then, these must be classified according to their importance in the problem studied. Using a comparison matrix (Tab. 1), the criteria are then compared in pairs, using the scale of values presented in (Tab. 2).

Table 1. Matrix of comparison and calculation of its own vector

Criterion	C_1	C_2	C_3	….	C_n	w_{iJ}
C_1	$1/\sum C_1$	$w12/\sum C$	$w31/\sum C_3$	….	$wn1/\sum C_n$	$\sum C_1/n$
C_2	$w12/\sum C$	$1/\sum C_2$	$w32/\sum C_3$	….	$wn2/\sum C_n$	$\sum C_2/n$
C_3	$w13/\sum C$	$w23/\sum C$	$1/\sum C_3$	….	$wn3/\sum C_n$	$\sum C_3/n$
….	….	….	….	….	….	….
C_n	$w1n/\sum C$	$w2n/\sum C$	$w3n/\sum C_3$	….	$1/\sum C_n$	$\sum C_N/n$
	$\sum C_1$	$\sum C_2$	$\sum C_3$	….	$\sum C_n$	

Explanations: when w_{iJ} represents the quantitative judgment of the pair of characteristics C_i, C_j, it is defined as follows:
condition 1: if $w_{ij} = \alpha$, then $w_{ij} = 1/\alpha$, $\alpha \neq 0$;
condition 2: if C_i is considered to be of relative importance equal to that of C_j, then $w_{ij} = 1$ and $w_{ii} = 1$, for all i.
Source: own elaboration.

Table 2. Determination of the degree of importance of factors by scale acc. to SAATY and VARGAS [1991]

Degrees of importance of each characteristic	Definition	Explanation
1	equal importance	two features contribute equally to the goal
3	low importance of one characteristic over another personal	experience and appreciation slightly favour one characteristic over another
5	strong or decisive importance	experience and appearance strongly favour one characteristic over another
7	very strong or attested importance	a characteristic is strongly favoured and its dominance is attested in practice
9	absolute importance	evidence favouring one characteristic over another is as convincing as possible
2, 4, 6, 8	values associated with intermediate judgments	when compromise is needed

Source: own elaboration.

This technique makes it possible to better evaluate the importance of the criteria over the others by comparing against one criterion at a time. The calculation of the eigenvectors of each criterion then makes it possible to obtain the weight which must be attributed to them and makes it possible to detect the errors of judgment during their prioritization [TUDES, YIGITER 2010].

The eigenvector of the matrix can be found by the following formula:

$$w_i = \left(TI_{j-1}^{n} w_{ij}\right)^{1/n}$$

In addition, it must be standardized so that the sum of its elements is equal to unity. For that, it is enough to calculate the proportion of each element with respect to the addition. $T = |w_1/\sum w_i \quad w_2/\sum w_i \; . \; . \, w_n/\sum i|$.

Let T be the normalized eigenvector used to quantify and evaluate the importance of each criterion. In order to test the consistency of the response that indicates whether the data is logically related to each other, SAATY [1977] proposes the following formula: $\lambda_{\max} = T \cdot w$.

Where w is calculated by adding the columns of the comparisons matrix.

The consistency of the order matrix (n) is evaluated. The comparisons made by this method are subjective and the AHP tolerates inconsistency by the amount of redundancy in the approach. If this consistency index fails to reach a required level, the responses to the comparisons can be re-examined. Then, the coherence index (CI) is calculated as follows: $CI = (\lambda\_max - n)/(n - 1)$. The coherence ratio ($CR$) is calculated by the equation: $CR = CI/CA$.

The CR is the ratio between CI and a random coherence index (CA). The index CA, presented in the Table 3, comes from a sample of 500 randomly managed positive inverse matrices, whose size reaches 11 by 11. A lower coherence ratio is considered acceptable at 0.10.

Table 3. Random coherence index (*CA*) values according to the order of the matrix

N	1	2	3	4	5	6	7	8	9	10	11
CA	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Source: own elaboration.

In our approach we have adopted the following steps:

a) select the most representative factors involved in erosive phenomena,
b) hierarchization,
c) weights of factors,
d) mapping,
e) synthetic map.

Select the most representative factors involved in erosive. This is the nature of the substrate, represented by the geology of shallow layers (soil erodibility), the topographic factor characterized by the slope criterion, the climatic factor represented by the intensity of daily rainfall and soil occupation characterized by vegetation cover.

SOIL ERODIBILITY FACTOR

Erodibility translates the sensitivity of a soil to erosion with regard to its intrinsic properties. This sensitivity is related on the structure and the texture of soil [WISCHMEIER *et al.* 1971; DUMAS 1965] and also the lithological formation of the ground which gives us information on the permeability (cohesion of the aggregates) [DUMAS 1965] – Figure 2.

To evaluate soil erodibility, we have mainly considered the lithological formation and the permeability of the ground (Tabs. 4, 5). Weights attributed to retained erodibility factors are assigned in the Tables 6 and 7.

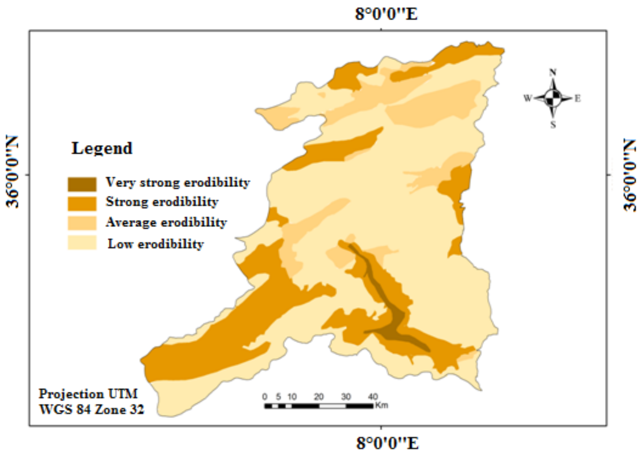

Fig. 2. Soil erodibility map; source: own elaboration

Table 4. Comparison matrix

Erodibility criterion	Very strong erodibility	Strong erodibility	Average erodibility	Low erodibility
Very strong erodibility	**1**	2	5	7
Strong erodibility	0.50	**1**	3	5
Average erodibility	0.25	0.33	**1**	3
Low erodibility	0.20	0.17	0.33	**1**
Total	1.95	3.50	9.33	16

Source: own elaboration.

Table 5. Calculation of the weight of the criterion (soil erodibility)

Erodibility criterion	Very strong erodibility	Strong erodibility	Average erodibility	Low erodibility	*Wi* (%)
Very strong erodibility	0.51	0.57	0.53	0.44	51.00
Strong erodibility	0.26	0.28	0.32	0.31	29.00
Average erodibility	0.13	0.09	0.11	0.19	13.00
Low erodibility	0.10	0.05	0.03	0.06	6.00
Total	1	1	1	1	100.00

Source: own elaboration.

Table 6. Calculation of the coherence ratio (*CR*)

Criterion	Erosive impact	C_1	C_2	C_3	C_4	Vector sum weight	Weight criteria	λ
C_1	very strong erodibility	1.00	2.00	5.00	7.00	2.16	0.51	4.23
C_2	strong erodibility	0.50	1.00	3.00	5.00	1.23	0.29	4.24
C_3	average erodibility	0.25	0.33	1.00	3.00	0.53	0.13	4.07
C_4	low erodibility	0.20	0.17	0.33	1.00	0.25	0.06	4.17
	Total	1.00	1.00	1.00	1.00		1.00	16.71

Source: own elaboration.

Table 7. Nature and contribution of erodibility classes

Erosive impact	Class
Very strong erodibility	4
Strong erodibility	3
Average erodibility	2
Low erodibility	1

Source: own elaboration.

So: $\lambda_{max} = 4.18$, $CI = 0.06$, $CA = 0.90$, $CR = 0.07$.
We have used the same approach for the other parameters.

TOPOGRAPHIC FACTOR

Using the Digital Terrain Model (DTM), we have drawing the slopes map through the Arc Gis software. For each class of slope is assigned an index varying between 1 and 4 [AKÉ *et al*. 2012; POESEN, HOOKE 1997] (Fig. 3, Tab. 8).

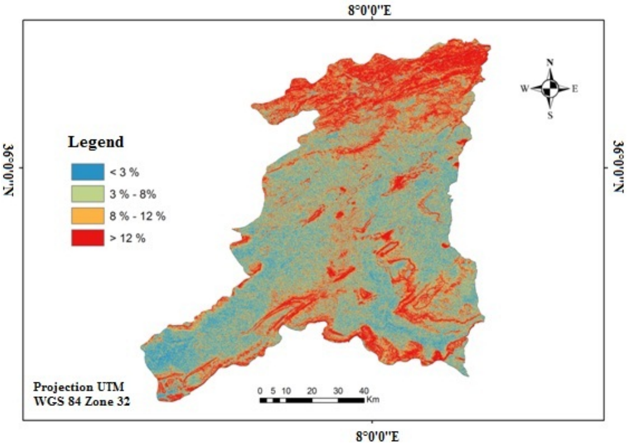

Fig. 3. Map of slope classes; source: own elaboration

Table 8. Nature and contribution of slope classes

Class limit	Erosive impact	Class
0–3%	low	1
3–8%	medium	2
8–12%	strong	3
>12%	very strong	4

Source: own elaboration.

CLIMATIC FACTOR

Due to the absence of rainfall records of 30 min at the rainfall stations installed in the study area, we have used maximum daily rainfall, which play a very important role and can promote strong erosion. However, if the intensity is high, the erosive risk is strong and if the intensity is low, the erosive risk is weak (Fig. 4, Tab. 9).

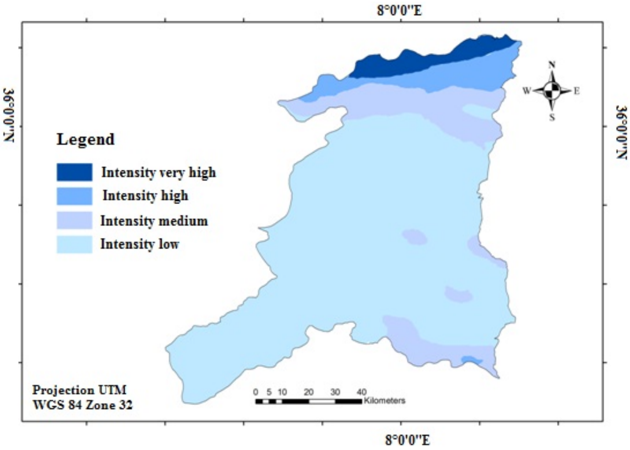

Fig. 4. Map of rainfall intensity; source: own elaboration

Table 9. Nature and contribution of rain classes

Rainfall intensity	Erosive impact	Class
<60 mm	low	1
60–70 mm	medium	2
70–80 mm	high	3
>80 mm	very high	4

Source: own elaboration.

LAND OCCUPATION

Based on satellite images and data collected from the agricultural and forest conservation services of the Tébessa and Souk Ahras wilaya, a map of land cover has been drawing through a classification taking into account field observations (Fig. 5, Tab. 10).

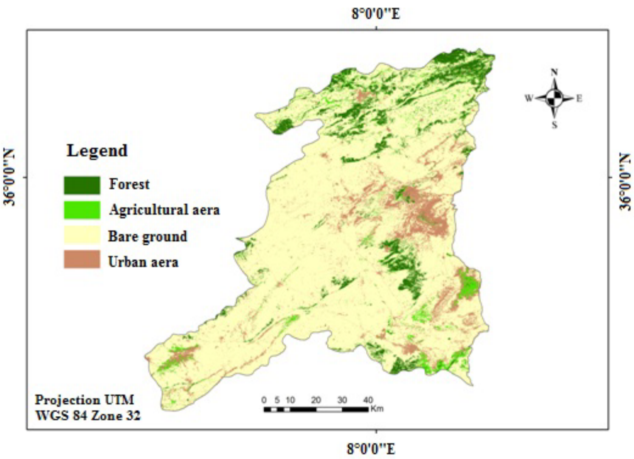

Fig. 5. Map of land occupation; source: own elaboration

Table 10. Nature and contribution of land use classes

Pattern	Erosive impact	Class
Urban area	low	1
Forest	average	2
Agricultural area	fort	3
Bare ground	very strong	4

Source: own elaboration.

Hierarchization. The hierarchization of the role of each factor at the spatial scale, through the attribution of an index following a matrix of comparison according to the importance of the parameters: weak = 1, average = 2, strong = 3 and very strong = 4 acc. to HUDSON [1996], GARCIA-RUIZ *et al.* [1996], POESEN and HOOKE [1997] and AKÉ *et al*. [2012].

Weights of factors. The weights attributed to the factors are indicated as the knowledge of the study area and the importance of the various factors in the process of erosion. Then it is necessary to calculate the coherence ratio (*CR*) to indicate the reliability of judgments of the calculated matrix acc. to SAATY [1977] or the *CR* value less than 0.1 (10%) (Tab. 11).

Table 11. Comparison matrix developed by the AHP method

Criterion	Soil erodibility	Slope	Rain	Land cover
Soil erodibility	1	3	5	7
Slope	1/2	1	3	6
Rain	1/4	1/3	1	3
Land cover	1/5	1/6	1/4	1

Source: own elaboration.

The coherence ratio (*CR*) is calculated by the equation:

$$CR = CI/RI \tag{1}$$

With coherence ratio (*RC*), random index (*RI*) developed by SAATY [1977] and the consistency index (*CI*) calculated by the equation (2):

$$CI = \lambda_{\max} - n/(n-1) \tag{2}$$

Where: $\lambda_{\max}$ = maximum eigenvalue of each factor of the matrix, *n* = the size of the matrix.

Mapping. Integration of cartographic and descriptive data of the factors influencing the water erosion process in a GIS.

Synthetic map. Establishment of the synthetic map of erosion conditions, applying the AHP method.

RESULTS AND DISCUSSION

After having realized the different matrixes, we have needed to relativize the behaviour of the different classes. The weights index (*wi*) expressed by the matrix were later appended to the different maps in the raster format by the reclassification operation of the Spatial Analyst extension (Arc-Gis). Then, we developed the matrix of comparison between the various decisive factors, as well as the weighting factor of each one, during the erosion. From the matrix made for the different factors, we calculated the normalized weight for each factor and also the consistency ratio according to the Saaty equation [SAATY 1977], the results are presented in Tables 12 and 13).

Table 12. Weighting calculation of all criteria used

Criterion	Soil erodibility	Slope	Rain	Land use
Soil erodibility	1	3	5	7
Slope	1/2	1	3	6
Rain	1/4	1/3	1	3
Land use	1/5	1/6	1/4	1
Standardized weight	0.53	0.29	0.12	0.06
CR = 0.09				

Explanation: *CR* = coherence ratio.
Source: own study.

According to the results obtained in Tables 13 and 14, the map of erosion hazard (Fig. 6) was carried out by Arc-Gis 10 according to the Equation (3):

$$\text{Erosion hazard} = 0.53\ \text{erosion} + 0.29\ \text{slope} + 0.12\ \text{daily rainfall} + 0.06\ \text{land use} \tag{3}$$

Erosion sensitivity analysis in the Medjerda watershed is carried out using the AHP method. The criteria used, in order of priority: soil erodibility, slope, intensity of rainfall and land use, their weights are calculated respectively as 53, 29, 12 and 6%, knowing that the coefficient of coherence (*CR*) is like 0.09. This indicates a reasonable level of consistency in the pair wise comparison of the different factors. The raster layer of each parameter used is multiplied by their given weight and adds them together using an arithmetic weighted sum overlay tool in Arc-GIS software. The combined map is reclassified into four classes as follows: very high, high, medium and low (Fig. 6).

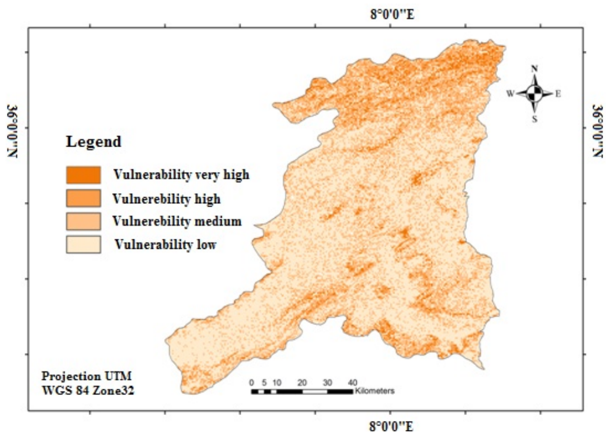

Fig. 6. Vulnerability to water erosion map in the Medjerda watershed source: own study

Based on the illustrated erosion hazard map and on the basis of weighted combined factors taken into account, we assert that the most important parameters are strongly related to slope and lithology (soil erodibility). As a result, areas with very high to high vulnerability are mainly located in the northern part of the catchment (where relief is very important), and some isolated areas in the center. On the other hand, a relatively lower area and low to moderate erosion dominate the entire southern part of the study area.

Table 13. Calculation results of the coherence ratio (*CR*)

Criterion	Factor	C_1	C_2	C_3	C_4	Vector sum weight	Weight criteria	λ
C_1	soil erodibility	1.00	3.00	5.00	7.00	2.42	0.53	4.57
C_2	slope	0.50	1.00	3.00	6.00	1.27	0.29	4.38
C_3	rain	0.25	0.33	1.00	3.00	0.53	0.12	4.42
C_4	land use	0.20	0.16	0.25	1.00	0.25	0.06	4.17
	total	1.00	1.00	1.00	1.00		1.00	17.54

Source: own study.

We would like to point out that this map was the first achievement in the study area, which did not allow us to compare it to other erosion maps established by other approaches.

CONCLUSIONS

The analytic hierarchy process (AHP) allowed us to have a spatialization and a localization of erosion-sensitive areas in the Medjerda watershed. Then the vulnerability map showed the extent of environmental degradation. From the distribution map of erosive hazards, we have identified four classes of vulnerability, areas with very high to high vulnerability are mainly in the northern part of the watershed (where the relief is very important), and some areas isolated in the center of watershed. In contrast, relatively low areas with low to moderate erosion dominate the entire southern part of the study area. Consequently, the impact of the degradation of the environment begins to be noticed in the dam of Ain Dalia (Souk Ahras) and the dam of Tarfa and Batoum (Mellegue Amont).

In addition, it seems to us very important to highlight the perspectives of our research which will enable watershed management organizations to use the results obtained to avoid siltation of dams and reduce soil degradation in the future.

REFERENCES

AKE G.E., KOUADIO B.H., ADJA M.G., ETTIEN J.B., EFFEBI K.R., BIEMI J. 2012. Cartographie de la vulnérabilité multifactorielle à l'érosion hydrique des sols de la région de Bonoua (Sud-Est de la Côte d'Ivoire) [Mapping of the multifactorial vulnerability to water erosion of soils in the region of Bonoua (Sud-Est de la Côte d'Ivoire)]. Physio-Géo. Vol. 6 p. 23–42. DOI 10.4000/physio-geo.2285.

BELARBI F., BOUCHELKIA H., REMINI B., BENMANSOUR A. 2018. Quantification and study of monthly variation of suspended sediment loads in Tafna basin Algeria. Journal of Water and Land Development. No. 37 (IV–VI) p. 29–38. DOI 10.2478/jwld-2018-0022.

BELLOULA M. 2008. Modélisation des écoulements et perspectives de prévention contre les risques d'inondation dans quelques bassins de la Medjerda (Confins Algéro-Tunisiens) [Modeling of flows and perspectives of prevention against flood risks in some Medjerda basins (Confins Algéro-Tunisiens)]. MSc Thesis. Université El Hadj Lakhdar pp. 166.

BENCHETRIT M. 1972. L'érosion actuelle et ses conséquences sur l'aménagement en Algérie [The current erosion and its consequences on planning in Algeria]. Paris, France. Universite de Poitiers pp. 217.

BOU KHEIR R., GIRARD M.C., SHABAN A., KHAWLE M., FAOUR G., DARWISH T. 2001a. Apport de la télédétection pour la modélisation de l'érosion hydrique des sols dans la région côtière du Liban [Contribution of remote sensing to the modeling of soil-water erosion on the coastal region of Lebanon]. Télédétection. Vol. 2. No. 2 p. 79–90.

BOU KHEIR R., GIRARD M.C., KHAWLE M., ABDALLAH C. 2001b. Érosion hydrique des sols dans les milieux méditerranéens : une revue bibliographique [Soil-water erosion in Mediterranean environments: A bibliographic review]. Étude et Gestion des Sols. Vol. 8. No. 4 p. 231–245.

CHAKHAR S., MOUSSEAU V. 2007. Spatial multicriteria decision making. In: Encyclopedia of geographic information science. Ed. K. Kemp. Newbury Park. Sage Publ. Inc. p. 747–753.

DROBNE S., LISEC A. 2009. Multi-attribute decision analysis in GIS: Weighted linear combination and ordered weighted averaging. Informatica. Vol. 33 p. 459–474.

DUMAS J. 1965. Relation entre l'érodibilité des sols et leurs caractéristiques analytiques [Relationship between the erodibility of soils and their analytical characteristics]. Cahiers ORSTOM. Série Pédologie. Vol. 3. No. 4 p. 307–333.

GARCIA-RUIZ J., LASANTA T., RUIZ-FLANO P., ORTIZA I., WHITE S., GONZALEZ C., ARTI C. 1996. Land use changes and sustainable development in mountain areas: A case study in the Spanish Pyrenees. Landscape Ecology. Vol. 11. No. 5 p. 267–277.

GRANDMONT K. 2013. Utilisation de systèmes d'information géographique pour l'évaluation des risques liés à la dégradation du pergélisol. Étude de cas : Tasiujaq, Nunavik, Québec [Use of geographic information systems to assess the risks associated with permafrost degradation. Case study: Tasiujaq, Nunavik, Québec]. MSc Thesis. Université de Montréal pp. 85.

HUDSON N. 1996. Mesures de terrain de l'érosion et de l'écoulement des eaux de surface [Field measurements of erosion and surface water flow]. Bulletin Pédologique. FAO. Vol. 68. ISBN 9252034064 pp. 153.

PAN J., WEN Y. 2014. Estimation of soil erosion using RUSLE in Caijiamiao watershed, China. Natural Hazards. Vol. 71 p. 2187–2205. DOI 10.1007/s11069-013-1006-2.

LU D., LI G., VALLADARES G.S., BATISTELLA M. 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia: Using RUSLE, remote sensing and GIS. Journal of Land Degradation and Development. Vol. 15. Iss. 5 p. 499–512. DOI 10.1002/ldr.634.

POESEN J.W.A., HOOKE J.M. 1997. Erosion, flooding and channel management in Mediterranean environments of Southern Europe. Progress in Physical Geography: Earth and Environment. Vol. 21. Iss. 2 p. 157–199. DOI 10.1177/030913339702100201.

RAMOS A., CUNHA L. CUNHA P.P. 2014. Application de la Méthode de l'Analyse Multicritère Hiérarchique à l'étude des glissements de terrain dans la région littorale du centre du Portugal: Figueira da Foz–Nazaré [Analytic hierarchy process (AHP) applied to the landslides study in a coastal area of the central Portugal: Figueira da Foz – Nazaré]. Geo-Eco-Trop. Vol. 38. Iss. 1 p. 33–44.

REMINI B. 2000. L'envasement des barrages : quelques exemples algeriens [The silting up of dams: some Algerian examples]. Bulletin du Réseau Erosion. Vol. 20 p. 165–171.

SAATY T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology. Vol. 15. Iss. 3 p. 234–281. DOI 10.1016/0022-2496(77)90033-5.

SAATY T.L., VARGAS L.G. 1991. Prediction, projection, and forecasting: Applications of the analytic hierarchy process in economics, finance, politics, games and sports. Boston. Kluwer Academic Publishers. ISBN 9780792391043 pp. 251.

SAATY T.L., SODENKAMP M. 2010. The Analytic Hierarchy and Analytic Network Measurement Processes: The measurement of intangibles: Decision making under benefits, opportunities, costs and risks. In: Handbook of multicriteria analysis. Eds. C. Zopounidis, P.M. Pardalos. Berlin, Heidelberg. Springer-Verlag p. 91–166.

SELMI K., KHANCHOUL K. 2016. Sediment load estimation in the Mellegue catchment, Algeria. Journal of Water and Land Development. No. 31 (X–XII) p. 129–137. DOI 10.1515/jwld-2016-0044.

TEBBI F.Z., DRIDI H., KALLA M. 2018. Performance analysis of a reservoir in arid region. Case study: Babar reservoir, Aurs region, Algeria. Journal of Water and Land Development. No. 39 p. 141–146. DOI 10.2478/jwld-2018-0069.

TUDES S., YIGITER N.D. 2010. Preparation of land use planning model using GIS based on AHP: Case study Adana-Turkey. Bulletin of Engineering Geology and the Environment. Vol. 69. Iss. 2 p. 235–245. DOI 10.1007/s10064-009-0247-5.

WISCHMEIER W.H., JOHNSON C.B., CROSS B.V. 1971. A soil erodibility nomograph for farmland and construction sites. Journal Soil and Water Conservation. Vol. 26. Iss. 5 p. 189–192.

YALCIN A., REIS S., AYDINOGLU A.C., YOMRALIOGLU T. 2011. A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon, NE Turkey. Catena. Vol. 85. Iss. 3 p. 274–287. DOI 10.1016/j.catena.2011.01.014.