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Assessing soil loss using GIS based RUSLE methodology. Case of the Bou Namoussa watershed – North-East of Algeria

Chemss Eddine BOUHADEB[1) ABCDE] ✉, Mohamed Redha MENANI[1) ADF], Hamza BOUGUERRA[2) BCE], Oussama DERDOUS[3) DE]

1) University Batna-2, Faculty of Technology, Laboratory of Mobilization and Management of Water Resources, Batna, Algeria; e-mail: chamsouhyd@hotmail.fr
2) University Abou Bakr Belkaid, Faculty of Technology, Department of Hydraulic, Laboratory No 25, BP 119 Tlemcen, Algeria; e-mail: bouguerrahamza23@gmail.com
3) University Kasdi Merbah, Faculty of Applied Sciences, Department of Civil and Hydraulic Engineering, Route Ghardaïa, BP 511, Ouargla, 30000, Algeria; e-mail: oussamaderdous@hotmail.fr

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Abstract

This study aims to estimating annual soil erosion rate and its spatial distribution in the Bou Namoussa watershed located in the North-East of Algeria by applying the revised universal soil loss equation (RUSLE) within a Geographical Information System environment (GIS). The application of the RUSLE model in different natural environments and on every scale takes into account five key factors namely: the rainfall erosivity, the soil erodibility, the steepness and length of slopes, the vegetation cover and the conservation support practices. Each of these factors was generated in GIS as a raster layer, their combination, resulted in the development of a soil loss map indicating an average erosion rate of 7.8 $t \cdot ha^{-1} \cdot y^{-1}$. The obtained soil loss map was classified into four erosion severity classes; low, moderate, high and very high severity representing respectively 40, 30.48, 22.59 and 6.89% of the total surface. The areas, showing moderate, high and very high erosion rates which represent more than half of the basin area were found generally located in regions having high erodibility soils, steep slopes and low vegetation cover. These areas should be considered as priorities in future erosion control programs in order to decrease the siltation rate in the Cheffia reservoir.

Key words: *Bou Namoussa watershed, GIS, RUSLE, siltation, soil erosion*

INTRODUCTION

In Algeria and across the neighbouring countries, water erosion problem acts as an aggressive natural phenomenon to soil and water resources [BOUGUERRA *et al.* 2017]. Results from previous studies, show that this phenomenon contributes progressively to the deterioration of agro-pedological regions, in fact huge amounts of soil are lost in river basins due to water erosion.

The accentuation of soil degradation depends on several natural and anthropogenic factors favouring the start and the development of erosion processes. These factors are divided into two categories, those that are of quasi-static nature (infiltration, erodibility and morphology...), and others that are time-varying (vegetation cover, land use, rainfall intensity and agricultural practices…) [BOUKHEIR *et al.* 2006; ROOSE, LELONG 1976; VRIELING 2005].

In Algeria, the areas prone to the risk of land degradation due to the desertification and the water erosion phenomena are estimated at $5·10^5$ km^2 which is more than 20% of the total surface of the country, $1.4·10^5$ of these areas at risk represents the northern mountains affected by water erosion, 3.2·105 km^2 of these areas represents the steppe zones threatened directly by desertification, while $4.1·10^4$ km^2 of it represents the forests threated by climate change impacts [MOSTEPHAOUI *et al.* 2013]. The annual loss of water storage capacity of dams is estimated at 20 hm^3 resulting from siltation [REMINI 2000].

The Bou Namoussa watershed is amongst the watersheds seriously affected by water erosion in Algeria, the bathymetric surveys of the Cheffia dam built on the Bou Namoussa Wadi indicate that the watershed is subject to an important siltation and increasingly intense, as the average loss in storage capacity of the Cheffia dam rose from 186 762 m^3·y^{-1} between 1965 and 1986 to 509 611.1 m^3·y^{-1} between 1986 and 2004.

To improve the fight against this phenomenon, it is necessary to identify its causes, consequences and to elaborate a soil loss map which locates high risk areas requiring priority interventions.

The Revised Universal Soil Loss Equation (RUSLE) can be used for evaluating and quantifying soil erosion in view of its universal adaptation, it is an empirical and spatialized model [RENARD *et al.* 1997] which was proposed by WISCHMEIER and SMITH [1978]. The RUSLE model takes into account five factors to evaluate soil loss which are: rainfall erosivity, soil erodibility, steepness and length of the slope, vegetation cover and the conservation support practices.

This study aims to estimate soil loss, and to highlight the areas subject to the risk of water erosion in the Bou Namoussa watershed. Furthermore, this study proposes an effective reproducible methodology for the application of the RUSLE model at a watershed scale. The principle of this methodology is to integrate into a Geographic Information System (GIS) all the soil erosion factors of the model. The combination of these factors according to the model's equation producing a soil loss map which depicts different degrees of vulnerability of soil to erosion.

The results obtained from this study, can assist the decision-makers in the implementation of soil management and conservation practices which is crucial in managing and protecting soil and water resources.

STUDY AREA

The Bou Namoussa watershed is located in the South of Taref city at the extreme North-East of Algeria, It forms the northerly side of the final stretch of the septentrional Atlas-Tellian chain which is composed by the mountains of Medjerdah in the Algerian part, and the mountains of Krounirio and Ghardimaou in Tunisia.

The Bou Namoussa watershed is part of Constantinois eastern coastal watershed, it covers an area of 575 km^2 and a perimeter of 176 km between longitudes 7°94' and 8°31' E and latitudes 36°38' and 36°69' N (Fig. 1). A portion of the Bou Namoussa watershed is located in the Tunisian territory covering the plain of Ain El Karma. This watershed is dominated by mountainous terrains, where the altitudes reach 808 m at Jebel Souani, 1406 m at Jebel M'Sid, 1015 m at Kef El Boum and 740 m at Draa Safsaf.

WATERSHED CHARACTERISTICS

The Bou Namoussa watershed has a circular and slightly elongated shape, oriented towards the geographical North. The study area is characterized by varied and very uneven terrains. Altitudes vary between 153 m at the outlet and 1405 m at the highest point of the watershed – Jebel M'Sid (Fig. 1).

The basin is drained by two important wadis – Bouhadjar Wadi and Kebir Wadi which constitute the major tributaries of the Bou Namoussa Wadi. This latter flows northward and feeds one of the largest dams in the region – Cheffia dam.

The hydrographic network is very dense and hierarchical; the drainage density is of 3.16 km·km^{-2}, this high value is due to the presence of steep slopes and surface exposures of low permeability favouring land degradation by the action of runoff (Fig. 2).

CLIMATE

The watershed is exposed to a wet, mild, Mediterranean climate characterized by rainy and cold winters and dry and hot summers. The mean annual rainfall ranges from 644 mm to 932 mm, January is the most rainy month with an inter-annual average rainfall of 680 mm recorded between 1970/1971 and 2011/2012.

Thermal variations emphasize that January and February are the coldest months with average temperatures of about 8°C. While, the hottest months are July and August with average temperatures of about 29.7°C.

SOIL

The Bou Namoussa watershed is dominated by podzolic soils (Fig. 3). Five classes of soils were distinguished; (i) podzolic soil under cork oak forests, located on reliefs whose altitudes are between 800 and 1405 m; it is formed on the sandstones of Numidia, on their screes, on the sandstone beds of the upper part of the Numidia clays which have light and sandy surface-soils; (ii) calcareous soil which can be included in a one master soil horizon rich in limestone, in light and permeable textures, in quaternary gravel formations, in sand and in silt. (iii) alluvial soil which is constituted by alluvial deposits with an undifferentiated profile, of continental Quaternary alluvium formations, terraces deposits in which the vegetation is still herbaceous; (iv) vertisols with high clay

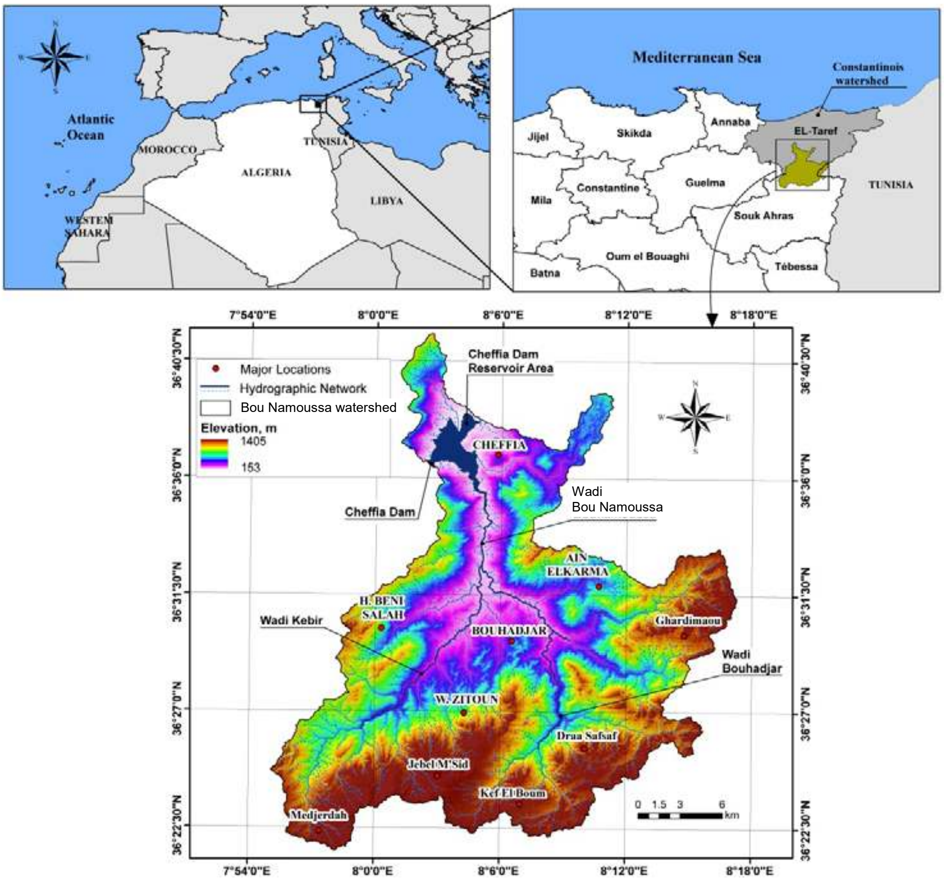

Fig. 1. Localization of the Bou Namoussa watershed; source: own elaboration

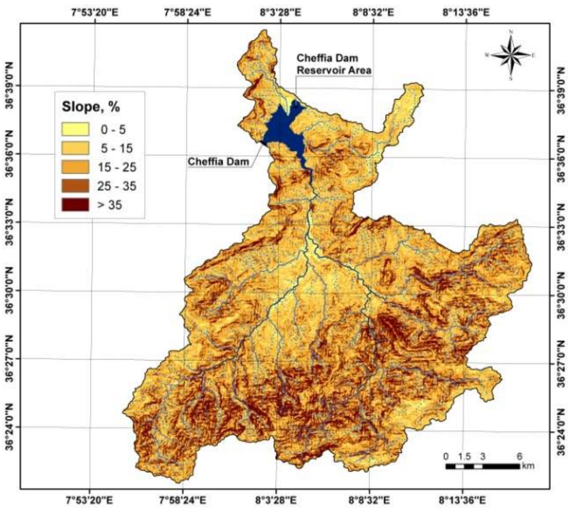

Fig. 2. Slope map of the study area; source: own elaboration

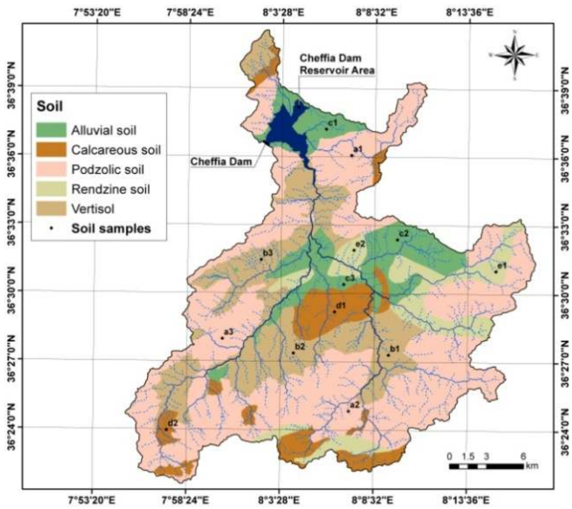

Fig. 3. Soil map of the study area; source: own elaboration based on the soil map of Algeria, Constantinian side [DURAND, BARBUT 1948]

content located on the reliefs lower than 800 m, and occupying 20% of the watershed area; (v) rendzine of a humus-bearing horizon, which is directly set on carbonate bedrock.

LAND USE

The Bou Namoussa watershed is characterised by the diversity of its natural vegetation:

– more than half of the basin (52%) is occupied by forest vegetations consisting primarily of cork oak and zeen oak, which are mainly localized in the upper and the middle part of the watershed (Fig. 4);
– the annual crops, dominated by cereals represents 19.30% of the total area, scattered mainly in the centre of the watershed;
– then rangelands occupy approximately 15.06% of the total area;

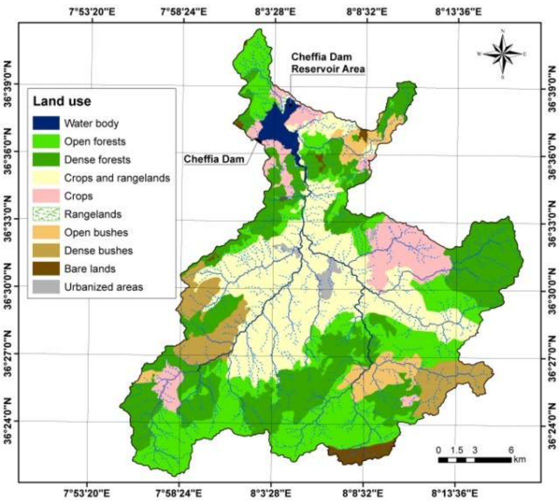

Fig. 4. Land use map of the study area; source: own elaboration

– the bushes represents a percentage of 10.60% of the watershed, these bushes indicate the relatively advanced stage of the forest degradation;
– the rest 3.09% of the watershed is occupied by bare lands and urbanized areas.

METHODS

Several empirical models have been developed for estimating soil erosion in watersheds, among the most used during the past 30 years there is the Universal Soil Loss Equation (USLE) and its revised version (RUSLE) that has been employed in the case of study. The RUSLE is an empirical model for the prediction of long term average annual rate of soil erosion (expressed in $t \cdot ha^{-1} \cdot y^{-1}$), by combining several factors having a bearing on the erosion velocity, namely; rainfall erosivity, soil erodibility, steepness and length of the slope (topography), vegetation cover and conservation support practices. The model's equation is in the form:

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (1)$$

Where: A = the computed amount of the average soil loss ($t \cdot ha^{-1} \cdot y^{-1}$); R = is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$); K = the soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$); LS = is the topographic factor (dimensionless); C = is cover management factor (dimensionless); P = is conservation support practice factor (dimensionless).

In this study, the spatial distribution of soil loss was obtained by coupling RUSLE model and GIS; the soil erosion factors were generated in GIS platform in the form of thematic maps and then integrated based on RUSLE equation as presented in the flowchart (Fig. 5).

RAINFALL EROSIVITY FACTOR (*R*)

The rainfall erosivity factor (R) is a climatic factor that reflects the effect of rainfall intensity on soil erosion. According to the equation proposed by WISCHMEIER and SMITH [1978] its calculation requires the determination of the total rainfall kinetic energy Ec ($mm \cdot h^{-1}$) and the peak rainfall intensity in 30 minute consecutive ($J \cdot m^{-2} \cdot mm^{-1}$).

These data are not available within the rainfall stations that are in or near the watershed. In fact, only monthly and annual rainfall data sets are available at these stations, thus it is not possible to calculate the R factor using this equation. To overcome the lack of detailed rainfall data, we employed an alternative mean consisting of the equation of FAO [1987], which involves only monthly and annual precipitation data sets, this equation has been widely applied in the Maghreb region (SADIKI et *al.* [2004] in Morocco and TOUMI *et al.* [2013] in Algeria), it is expressed as:

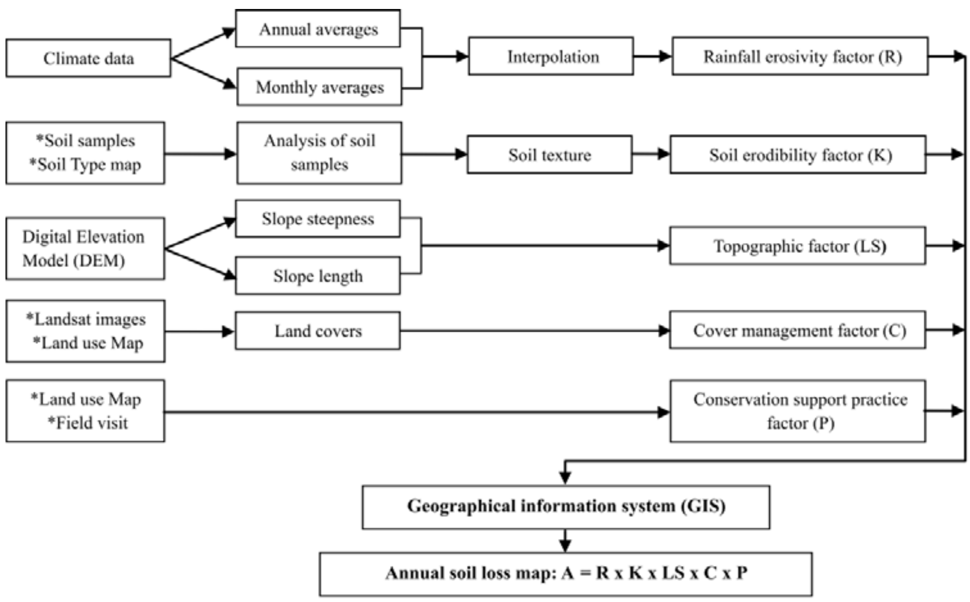

Fig. 5. Flowchart of the GIS based RUSLE methodology; source: own study

$$\log R = 1.74 \log \Sigma(Pi^2 \cdot P^{-1}) + 1.29 \quad (2)$$

Where: Pi = is the monthly rainfall; P = is the annual rainfall in mm.

The *R* factor is calculated using data of 42 years between 1970/1971 and 2011/2012 collected from 6 rainfall stations, spread over the study area. Then, the results were interpolated throughout the entire watershed.

TOPOGRAPHIC FACTOR (*LS*)

The *LS* factor reflects the effect of slope length (*L*) and slope steepness (*S*) on erosion process [MCCOOL *et al.* The *L* and *S* factors, generally grouped together as topographic factor (*LS*), have significant influence on soil erosion process [ROOSE 1994].

In this study, the determination of *LS* factor were conducted, by firstly generating flow-accumulation and the slope maps in GIS environment from a digital elevation model (DEM) of the study area downloaded from ASTER satellite data (30 m resolution). Then, *LS* factor was determined by considering slope length (in meters) and slope incline (in percentage) of each parcel. The Equation (3) was adopted to calculate *LS* factor as proposed by WISCHMEIER and SMITH [1978].

$$LS = (X \cdot 22.13^{-1})^m \, (0.065 + 0.045S + 0.065S^2) \quad (3)$$

where: X = is slope length (m); S = is angle of slope (%); m = dimensionless exponent that depends on slope steepness as follow:
- $S < 1\%$ – $m = 0.2$;
- $1\% \leq S \leq 3\%$ – $m = 0.3$;
- $3\% \leq S \leq 5\%$ – $m = 0.4$;
- $S \geq 5\%$ – $m = 0.5$.

$$S = 10.8 \sin \theta + 0.03 \quad S < 9\% \quad (4)$$

$$S = 16.8 \sin \theta + 0.50 \quad S \geq 9\% \quad (5)$$

SOIL ERODIBILITY FACTOR (*K*)

The *K* factor represents the susceptibility of soil particles to detachment and movement by water, which depends on the physical, chemical and pedologic characteristics of soil.

In the present study, the soil data used to generate the spatial distribution of *K* factor were extracted from the soil map (Fig. 4) and from 13 soil samples (0–25 cm deep) distributed over the watershed surface in such way that each soil type is represented by 2 or 3 samples, the samples were then analysed in laboratory to determine the physical characteristics and the organic matter content of soil. The obtained values were assigned and generalized to each type of soil. Soil textures were classified based on the textural triangle developed by the United States Department of Agriculture USDA [BROWN 2003]. Then the corresponding *K* values for each soil texture were estimated with the help of the table of correspondence of STONE and HILBORNE [2000].

COVER MANAGEMENT FACTOR (*C*)

The *C* factor reflects the effect of land cover on soil erosion process. It is probably the most important factor in RUSLE since it represents conditions that can easily be managed to prevent or reduce soil loss [MCCOOL *et al.* 1995].

The factor *C* which depends on the density, height of vegetation and the cropping system was determined in this study on the basis of the land use map of the study area. The land use map was generated from Landsat-8 images of 2005 which was processed, classified and validated using data derived from surveys conducted on the city of El Taref. The *C* factor for cultivated lands was attributed based on the studies of CORMARY and MASSON [1963] conducted in Tunisia based on information on crop patterns and crop rotations. For other land uses such as forests, shrublands and pasturelands values of the *C* factor were attributed based on WISCHMEIER and SMITH [1978] tables.

CONSERVATION SUPPORT PRACTICE FACTOR (*P*)

The *P* factor reflects the effects of agricultural conservation practices such as contouring, strip cropping and ridging that decrease the erosive impact of rainfall and runoff and thus decrease the amount of soil erosion [PAYET *et al.* 2011]. The values of *P* factor varies from 0 to 1, a value approaching to 1 is assigned to lands with no erosion control practices while a value of about 0.1 is assigned to low-sloping lands with tied ridges [ROOSE 1996].

Regarding the Bou Namoussa watershed, no major erosion control practices are used, thus the *P* factor was assigned a value of 1.0 over the entire area.

RESULTS AND DISCUSSION

R-FACTOR

Using rainfall data from six rainfall stations (Tab. 1), *R* factors values of each station were estimated. Subsequently, *R* factor values of the entire watershed were interpolated using Ordinary Kriging interpolation within GIS. The spatial distribution of rainfall erosivity shows that the values of *R* factor vary from 153 to 207 a function of rainfall characteristics. The lowest *R* values were recorded in the central part of the watershed and the highest were recorded in the south-western part. According to the Figure 6, 80% of the study area is subject to high rainfall erosivity since it showed values of *R* factor higher than 160.

K-FACTOR

The spatial distribution of soil erodibility (Fig. 7) was obtained by assigning to each soil texture a respective *K* value according to the table of STONE and HILBORNE [2000] (Tab. 2). The *K* values ranged from 0.028 to 0.05.

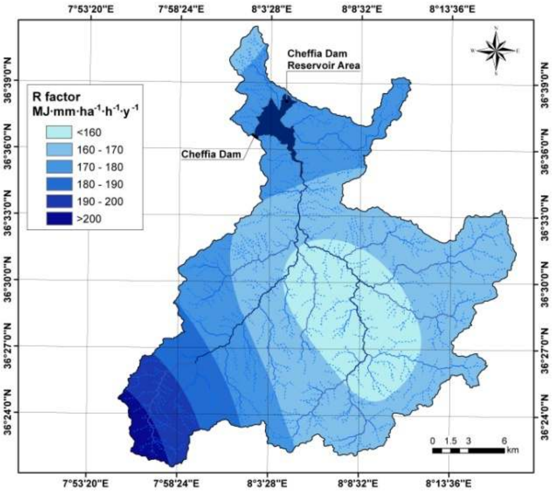

Fig. 6. *R* factor map of the study area;
source: own study

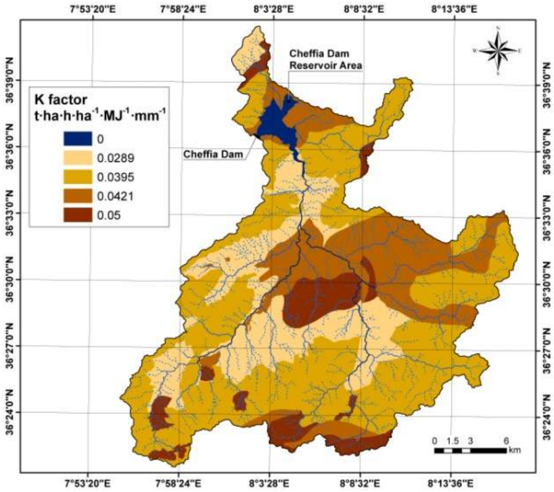

Fig. 7. *K* factor map of the study area;
source: own study

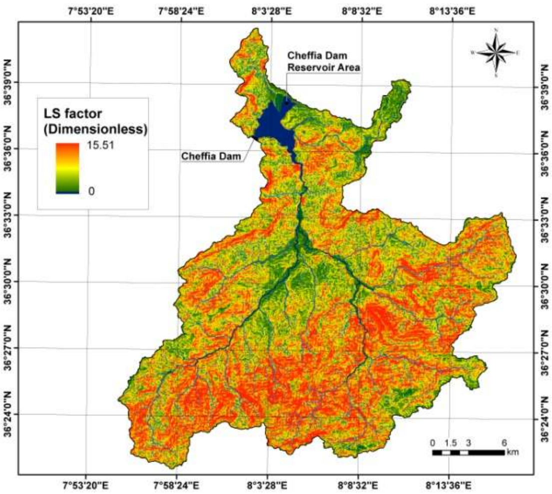

Fig. 8. *LS* factor map of the study area;
source: own study

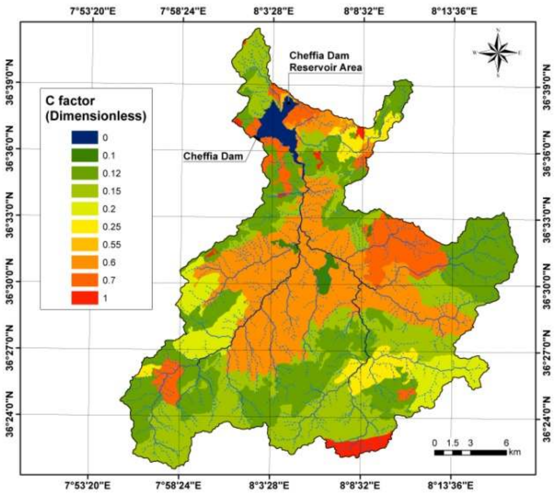

Fig. 9. *C* factor map of the study area;
source: own study

Table 1. Average annual rainfall and corresponding *R* factor values (period: 1970–2012)

Station	DMS coordinates			Annual rainfall mm	*R* factor MJ·mm·ha^{-1}·h^{-1}·y^{-1}
	E	N	elevation m		
Mechroha	7°50'17"	36°21'48"	750	1 133.8	238.5
Ain El Karma	8°11'25"	36°35'22"	280	719.4	171.2
Asfour	7°58'14"	36°40'16"	16	599.7	149.9
Cheffia	8°01'43"	36°36'57"	170	809.5	184.6
Bouhadjar	8°06'07"	36°30'22"	300	617.8	150.8
Ain Seynour	7°52'30"	36°19'25"	792	990.5	219.1

Source: own study.

Table 2. *K* values according to the soil type

Soil type	Texture	*K* factor t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}
Alluvial soil	silty clay loam	0.0421
Calcareous soil	silt loam	0.0500
Podzolic soil	loam	0.0395
Rendzine soil	silty clay loam	0.0421
Vertisol	clay	0.0289

Source: own study.

The highest values of *K* factor are associated with the soils more vulnerable to erosion which are in this study the silt loam soils that extend into the central and upper part watershed. On the other hand, the soils with the lowest *K* value are associated with the clay soils. Generally, the study area soils are considered highly susceptible to water erosion with respect to the average of their erodibility *K* factor which is estimated at 0.038.

LS-FACTOR

According to the calculations, *LS* factor values were found ranging from 0 to 15.51 with an average of 3.5 (Fig. 8). The obtained map showed that *LS* factor is directly related with the topography. The higher values occur mainly in the mountainous areas of upper valley, whereas less values ($LS < 5$) covered the central mild part of the Bou Namoussa watershed.

C-FACTOR

The map of *C* factor (Fig. 9) describes the effect of the different types of land use on the erosion process in the study area, the *C* factor values ranged from 0.10 to 1. Heavily vegetated areas with low human impacts are associated to the lowest *C* values (<0.2) and represent a better soil protection against water erosion. While the highest *C* values (>0.2) representing about 40% of the study area (Fig. 10) concern the regions with low plant cover which are highly erodible soils.

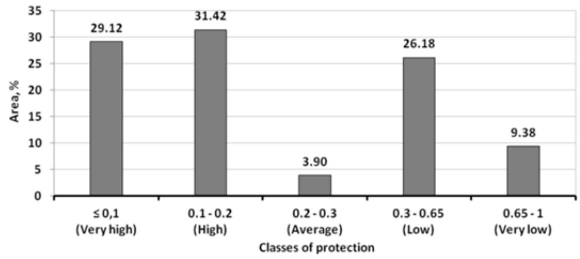

Fig. 10. Area of classes of *C* factor; source: own study

ESTIMATION OF POTENTIAL ANNUAL SOIL LOSS (*A*)

R, K, LS, C and *P* factors of the Bou Namoussa watershed were developed as raster layers in GIS. Their multiplication enabled estimating the potential annual soil loss. The average value of the estimated soil loss is 7.8 $t \cdot ha^{-1} \cdot y^{-1}$. In order to highlight the severity of soil loss through the study area the estimated soil loss was classified into five classes: very low, low, moderate, high and very high erosion based on the rate of erosion (Tab. 3).

Table 3. Soil erosion severity classes with average annual soil erosion rates

Soil erosion severity *A* $t \cdot ha^{-1} \cdot y^{-1}$	Area		Soil erosion classes
	ha	%	
<2.5	11 210.28	19.50	very low
2.5–5.0	11 810.50	20.54	low
5.0–10	17 528.81	30.48	moderate
10–20	12 988.47	22.59	high
>20	3 961.94	6.89	very high

Source: own study.

The classification (Fig. 11) indicates that the categories very low and low erosion describe 40% of the watershed area and associated with areas with mild slopes, adequately protected by vegetation cover. The areas under moderate erosion category which could be found in almost all areas describe 30.48% of the watershed. 22.59% of the study area is under high erosion severity, it consists mainly by agricultural lands with steep slopes. Very high erosion occurs in a few parts of the watershed, only in high erodibility soils with poor vegetation cover and steep reliefs.

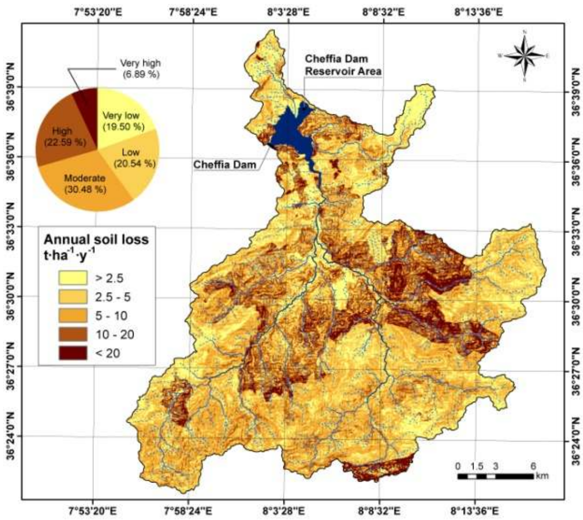

Fig. 11. The erosion severity map; source: own study

VALIDATION

The results obtained in this paper by applying RUSLE model need to be validated against real measurements of sedimentary transport, however, no such data exist actually at the Wadi Bou Namoussa. An alternative method was employed to overcome this deficiency; it consists on calculating the tonnage of sediment deposits using the following equation [CHEIKHA, GUEDDERI 2008]:

$$Ts = [(Vs \cdot D) + (Vrd \cdot C)]\, N^{-1} \tag{6}$$

Where: Ts = total sediment yield ($t \cdot y^{-1}$); Vs = the volume of the accumulated sediments between two bathymetric surveys (m^3); D = sediment density ($t \cdot m^{-3}$); Vrd = the volumes of water released during a flood event (m^3); C = average concentration of solid matters sediment loads of the released waters ($t \cdot m^{-3}$); N = number of years.

According to the bathymetric surveys conducted by the National Agency of Dams and Transfers (Fr. Agence Nationale des Barrage et Transfert – ANBT) in 1965, 1986 and 2004 the reservoir of Cheffia lost an average of 186 762 $m^3 \cdot y^{-1}$ between 1965 and 1986 and of 509 611 $m^3 \cdot y^{-1}$ between 1986 and 2004. During the entire period (39 years) the reservoir lost 13.09 10^6 m^3 of its volume due to the sedimentation which corresponds to an average loss of 335 769 $m^3 \cdot y^{-1}$ (Fig. 12). This amount corresponds to a total solid deposit of 335 769 $t \cdot y^{-1}$, if we consider a typical wet sediment density of 1. Moreover, during this period, total quantity of sediment of 82 421.6 $t \cdot y^{-1}$ was excavated from the Cheffia reservoir.

The estimation of the mean annual sedimentation since the impoundment of the Cheffia dam (1965) until 2004 results in a sediment yield of 7.2 $t \cdot ha^{-1} \cdot y^{-1}$. This value is relatively close to the value obtained by RUSLE, the difference between the two values is estimated at 7.70% which indicates certain

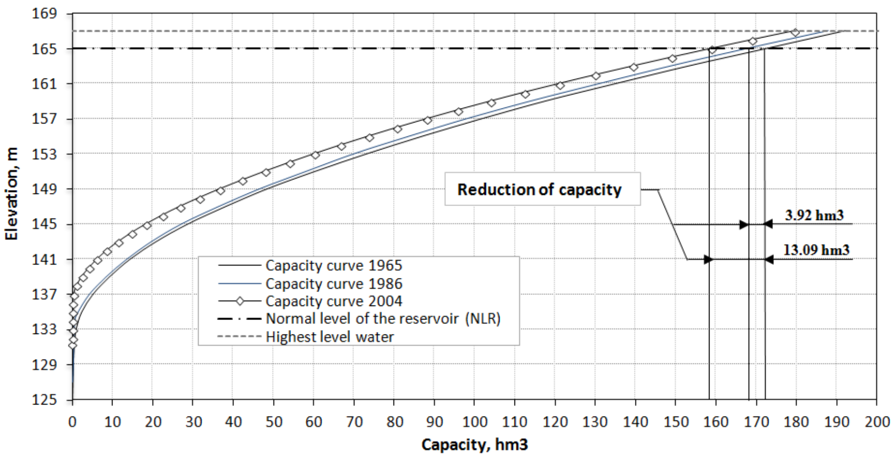

Fig. 12. Elevation capacity curve for Cheffia dam; source: own elaboration

compatibility between soil erosion rates estimated by the RUSLE model and by bathymetric measurements. The obtained difference is attributed to the operating limitations of the model, in fact the RUSLE model does not consider many phenomena such as landslides and channel erosion.

SUMMARY AND CONCLUSION

This study illustrates the application of the empirical soil erosion model RUSLE integrated with GIS for estimating the spatial distribution of soil erosion in the Bou Namoussa watershed in order to identify critical areas for erosion control measures. The results indicated that the watershed loses an average of 7.8 $t \cdot ha^{-1} \cdot y^{-1}$, this value is relatively close to the measured sediment yields derived from the bathymetric surveys of Cheffia dam.

A soil erosion severity map with five classes was elaborated based on the soil loss estimations in each grid cell of the watershed.The spatial distribution of erosion severity classes was 19.50% very low (<2.5 $t \cdot ha^{-1} \cdot y^{-1}$), 20.54% low (from 2.5 to 5 $t \cdot ha^{-1} \cdot y^{-1}$), 30.48% moderate (from 5 to 10 $t \cdot ha^{-1} \cdot y^{-1}$), 22.59% high (from 10 to 20 $t \cdot ha^{-1} \cdot y^{-1}$), and 6.89% very high (>20 $t \cdot ha^{-1} \cdot y^{-1}$). More than half of the watershed area depicts amounts of soil loss of more than 5 $t \cdot ha^{-1} \cdot y^{-1}$ resulting from the interaction of several factors, mainly the predominance of steep slopes and highly erodible soils combined with the high anthropogenic pressure of an agricultural nature, causing the loss of forest cover in favor of cover crops as well as the absence of erosion control measures.

The study results constitute valuable support that should help the decision-makers in implementing suitable soil conservation practices in order to reduce the amount of soil loss and thus reduce the siltation rate at the downstream reservoir. At a long-term scale, the results can be used in monitoring the impact of cropping systems and soil conservation practices on the erosion process in the Bou Namoussa watershed.

REFERENCES

BOUGUERRA H., BOUANANI A., KHANCHOUL K., DERDOUS O., TACHI S.E. 2017. Mapping erosion prone areas in the Bouhamdane watershed (Algeria) using the Revised Universal Soil Loss Equation through GIS. Journal of Water and Land Development. Vol. 32. Iss. 1 p. 13–23.

BOUKHEIR R., CERDO O., ABDALLAH C. 2006. Regional soil erosion risk mapping in Lebanon. The Journal of Geomorphology. Vol. 82. Iss. 3 p. 347–359.

BROWN R.B. 2003. Soil texture, soil science fact sheet SL29. Gainesville, Florida. Univ. of Florida, Institute of Food and Agricultural Sciences pp. 8.

CHEIKHA B.L., GUEDDERI M. 2008. Le bassin versant du Jannet (Tunisie): Evaluation des risques d'érosion hydrique [Jannet catchment area (Tunisia): Assessing water erosion risks]. Mappemonde Journal. Iss. 90 p. 1–11.

CORMARY Y., MASSON J. 1963. Application à un projet type de la formule de perte de sols de Wischmeier. Etude de conservation des eaux et du sol au Centre de recherches du génie rural de Tunisie [Application to a project type the soil loss equation of Wischmeier. Study of water conservation and from the ground at the research centre of rural engineering of Tunisia]. Cahiers ORSTOM. Série Pédologie. Vol. 2. Iss. 3 p. 3–26.

DURAND M.J.H., BARBUT M.M. 1948. Carte des sols d'Algérie, coté Constantine [Soil map of Algeria, Constantinian side] [online]. [Access 20.07.2011]. Available at: http://eusoils.jrc.ec.europa.eu/Esdb_Archive/EuDASM/Africa/lists/y0_cdz.htm

FAO 1987. Aménagement des bassins versants [Management of watersheds] [online]. Rome. Food and Agriculture Organization. [Access 20.01.2017]. Available at: http://www.fao.org/docrep/006/AD071F/AD071F00.HTM

MCCOOL D.K., BROWN L.C., FOSTER G.R., MUTCHLER C.K., MEYER L.D. 2013. Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of the ASAE. Vol. 30. Iss. 5 p. 1387–1396.

MCCOOL D.K., PAPENDICK R.I., HAMMEL J.E. 1995. Surface residue management. In: Crop residue management to reduce erosion and improve soil quality. Eds. R.I. Papendick, W.C. Moldenhauer. USDA. Conservation Report. No 40 p. 10–16.

MOSTEPHAOUI T., MERDAS S., SAKAA B., HANAFI M.T., BENAZZOUZ M.T. 2013. Cartographie des risques d'érosion hydrique par l'application de l'équation universelle de pertes en sol à l'aide d'un système d'information géographique dans le bassin-versant d'el Hamel (Boussaâda) Algérie [Mapping of water Erosion risk by the application of Universal Soil Loss Equation using the geographic information systems in the El Hamel watershed (Boussaâda) Algeria]. Journal Algérien des Régions Arides. N° spécial. Vol. 201 p. 131–146.

PAYET E., DUMAS P., PENNOBER G. 2011. Modélisation de l'érosion hydrique des sols sur un bassin versant du sud-ouest de Madagascar, le Fiherenana [Modeling of soil water erosion in the southwestern of Madagascar watershed, Fiherenana] [online]. [Access 20.01.2012]. La revue électronique en sciences de l'environnement. Vol. 11. Iss. 3. Available at: http://journals.openedition.org/vertigo/12591

REMINI B. 2000. L'envasement des barrages. Quelques exemples Algeriens [The silting of dams. Some Algerian examples]. Bulletin du Réseau Erosion. No 20 p. 165–171.

RENARD K.G., FOSTER G.R., WEESIES G.A., MCCOOL D.K., YODER D.C. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Washington, DC. USDA. Agricultural Handbook. No 703 pp. 404.

ROOSE E. 1994. Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols [Introduction to the conservative management of water, biomass and soil fertility]. Bulletin pédologique de la FAO pp. 70.

ROOSE E. 1996. Land husbandry – Components and strategy. Soils Bulletin FAO. No 70 pp. 370.

ROOSE E.J., LELONG F. 1976. Les facteurs de l'érosion hydrique en Afrique Tropicale. Études sur petites parcelles expérimentales de sol [The factors of water erosion in tropical Africa. Studies on small experimental soil plots]. Revue de géographie physique et de géologie dynamique. Vol. 18. Iss. 4 p. 365–374.

SADIKI A., BOUHLASSA S., AUAJJAR J., FALEH A., MACAIRE J.J. 2004. Use of GIS for the evaluation and mapping of erosion risk by the Universal Soil Loss Equation in the Eastern Rif (Morocco): Boussouab watershed case study. Rabat. Scientific Institute Bulletin. Earth Sciences Series. Vol. 26 p. 69–79.

STONE R.P., HILLBORN D. 2000. Universal Soil Loss Equation, USLE. Ontario. Ministry of Agriculture, Food and Rural Affairs pp. 9.

TOUMI S., MEDDI M., MAHE G., BROU Y.T. 2013. Cartographie de l'érosion dans le bassin versant de l'Oued Mina en Algérie par télédétection et SIG [Remote sensing and GIS applied to the mapping of soil loss by erosion in theWadi Mina catchment]. Hydrological Sciences Journal. Vol. 58. Iss. 7 p. 1542–1558.

VRIELING A. 2005. Satellite remote sensing for water erosion assessment, a review. CATENA. Vol. 65. Iss. 1 p. 2–18.

WISCHMEIER W.H., SMITH D.D. 1978. Predicting rainfall erosion. A guide to conservation planning. USDA-ARS. Agriculture Handbook. No 537 pp. 58.

Chemss Eddine BOUHADEB, Mohamed Redha MENANI, Hamza BOUGUERRA, Oussama DERDOUS

Szacowanie strat gleby z zastosowaniem GIS i metodologii RUSLE – przykład zlewni Bou Namoussa w północno-wschodniej Algierii

STRESZCZENIE

Badania miały na celu oszacowanie rocznego tempa erozji gleb i jego przestrzennego zróżnicowania w zlewni Bou Namoussa w północnowschodniej Algierii z użyciem równania strat glebowych (RUSLE) w ramach systemu GIS. Aplikacja modelu RUSLE w różnych środowiskach naturalnych i w dowolnej skali uwzględnia 5 kluczowych czynników: zdolność erozyjną opadów, podatność gleb na erozję, nachylenie i długość stoków, pokrycie roślinnością i działania ochronne. Każdy z tych czynników został utworzony w GIS w formie warstwy rastrowej. Kombinacja tych warstw umożliwiła opracowanie mapy strat glebowych wskazującej średnie tempo strat równe 7,8 $Mg \cdot ha^{-1} \cdot rok^{-1}$. Wydzielono 4 klasy natężenia erozji: niskie, umiarkowane, wysokie i bardzo wysokie, reprezentowane odpowiednio na 40, 30,48, 22,59 i 6,89% całkowitej powierzchni. Obszary o umiarkowanym, wysokim i bardzo wysokim tempie erozji gleb pokrywające ponad połowę powierzchni zlewni były zlokalizowane głównie na glebach o wysokiej podatności na erozję, na stromych stokach i na terenach o ubogiej pokrywie roślinnej. Te obszary powinny być traktowane jako priorytetowe w trakcie konstruowania przyszłych programów ochrony przed erozją w celu zmniejszenia tempa zamulania zbiornika Cheffia.

Słowa kluczowe: *erozja gleb, GIS, RUSLE, zamulanie, zlewnia Bou Namoussa*