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QUANTITATIVE ANALYSIS OF WATER EROSION PROCESSES IN MARL SOILS IN THE OUED MINA WATERSHED

Neggaz Fatima Zohra* and Kouri Lakhdar

Biodiversity and Water and Soil Conservation Laboratory Abdelhamid Ibn Badis University, UMAB - Mostaganem, Algeria.

Abstract

The objective of our study is to spatialize a punctual model of water erosion quantification USLE, to locate sediment source sectors and priority areas for anti-erosion developments in the marl area of Oued Mina Watershed in Algeria. The approach adopted consists to develop a methodology, using the Geographic Information System (GIS) in order to map and evaluate quantitatively the water erosion. The Universal Soil Loss Equation (USLE) has been applied under its revised version RUSLE. The calculations are the result of modelling the main factors involved in water erosion. The erosion index R was calculated on the basis of Rango and Arnoldus (1987) formula, it varies between 42 and 74. The values of soil erosion factor K are between 0.060 and 0.46. A DEM with a resolution of 30m was used to generate the Topographic Factor LS. The values of C and P factors, which represent vegetation cover and erosion control practices, were calculated on the basis of the vegetation cover map and satellite images. The cross-referencing of the different thematic maps using the ARC GIS information system generated the soil loss map. The results obtained show that the intensity of erosion and the quantities of sediment produced vary mainly in function of current land use as well as the nature of the land and its slope. Priorities for management practices are fixed on the basis of the risk of soil erosion, and sediment transport downstream of the Oued Mina watershed.

Key words : watershed, Oued Mina, water erosion, quantification, Geographic Information System, RUSLE model.

Introduction

In Algeria, the loss of capacity of dam retention by its siltation is considered a crucial problem. Erosion of watersheds is the cause of siltation of hydraulic structures. The basin of Oued Mina is particularly rich in erosion forms. The studies carried out on its marl soils, the subject of our work, show a complexity of the phenomenon of water erosion, a significant heterogeneity of soils, and a very sparse or non-existent vegetation cover. Rainfall poorly distributed in both space and time (Kouri, 1993; Gomer, 1994; GTZ, 1996; Tecsul, 2006; Kouri *et al.*, 2010; Benchettouh, 2012; Neggaz, 2012; Toumi, 2013).

Over the years, the study methods of soil erosion have constantly evolved. The Universal Soil Loss Equation (USLE) has been modified and improved to give the revised model (RUSLE), which is one of the main approaches currently being developed. It uses the same USLE empirical principles, but includes many improvements, such as the use of monthly precipitation, irregular slopes, and improved calculations of the topographic factor LS by algorithms associated to GIS.

The experimental approach adopted consists in spatializing the universal equation of soil losses in USLE, under its revised version RUSLE. The calculations required mapping and analysis of the main factors involved in water erosion, namely: rainfall aggressiveness, soil erosion, terrain topography (inclination and slope length), vegetation cover and erosion control practices, which made it possible to estimate the amount of soil that could be detached annually at the pixel scale for the study area.

Materials and Methods

The Study Area

The Oued Mina watershed is located in the north-western part of Algeria, about 300 km from the capital.

****Author for correspondence :*** E-mail: neggaz_fatima@yahoo.fr

It covers an area of about 5,000 km2 (Fig.1). The tertiary marl area, our study site, represents one fifth of the total surface area of the basin. In this area the climate is semi-arid, rainfall varies from 200 to 500 mm/year, the hydrographic network is dense and branched, and the oueds are temporary with seasonal flow regime and discharge into the Oued Mina. The average altitude value is 449 m with a minimum of 133 m and a maximum of 949 m. Geology mainly includes marl formations. Agricultural areas cover 40% of the study area.

Calculation of the water erosion rate with USLE (Universal Soil Loss Equation)

According to the USLE, erosion is a multiplicative function of rainfall erosion (factor R), multiplied by the resistance of the environment, which includes K (soil erodibility), LS (topographic factor), C (vegetation cover) and P (erosion control practices).

(Erosion rate t /ha/year) = K * R * L * L * S * C * P

Rainfall erosivity factor (R)

The R factor, according to Wischmeier and Smith (1958; 1960), represents the product of kinetic energy (Ecin) and the maximum rainfall intensity in 30 minutes [mmh-1],R = Ecin i30.To overcome the insufficiency of rainfall data, in particular rainfall intensity at thirty minutes i30; some researchers (Kalman, 1967; Fournier, 1960; Arnoldus, 1980; Rango and Arnoldus, 1987) have developed alternative formulas, which only involve monthly and annual rainfall to determine the R factor.

The Rango and Arnoldus equation, adapted for North Africa and used by several researchers: (SEl-Bouqdaoui *et al.*, 2006; Chen *et al.*, 2008; Meddi, 2013; Kouadri *et al.*, 2016; Modeste *et al.*, 2016); was used to calculate the R factor in the study area.

Log R = 1.74 Log Σ (Pi2/P) + 1.29

- Pi : monthly precipitation

- P: annual precipitation

The Rango and Arnoldus formula is applied in thirteen (13) meteorological stations (Fig. 4). Although some of these stations are outside the study area, they are included in the interpolation; their proximity to the study area will improve the quality of the interpolation

The distribution map of the climatic aggressivity factor R is made according to the Ordinary KRIGEAGE principle, using the geographical statistical extension Analyst, ARC GIS. The semi-variogram was generated by a statistical model of the exponential type (Fig. 3).

Soil Erodibility factor (K)

According to Wischmeier and Smith (1962; 1971), soil erodibility depends essentially on the rate of organic matter, soil texture, structure and permeability. An equation based on the four parameters is used in the following form:

K =[0.00021 M 1.14 (12 - A)] +[0.0325 (S - 2)] +[0.025 (P - 3)]

-M : textural term = (%limon+ %fine sand) * (100 - Clay 100)

-A: the organic matter content

-S: soil structure code (1 to 4), 1 for a very fine grain structure and 4 for a massive block structure

-P: permeability code (1 to 6), ranging from 1 for fast draining soils to 6 for very slow draining soils.

To determine the values of the K factor in the study area, Soil analyses of thirty-three (33) samples selected from the map of lithological units were used (Fig. 5). Soil samples from both surface and subsoil horizons were collected at 3 points within the stations throughout the study area. Each station corresponds to a different soil class in the study area.

Topographic factor (LS)

The topographic factor, LS is defined as the product of the slope length L, and its inclination S, per unit area, being the standard wischmeier plot with a length of 22.1m and a slope of 9%. Modifications introduced to the Wischmeier and Smith 1960 formula (LS = (l/22.1) m * (0.065+0.045S+0.065S2, m[0.2 to 0.5]) by several authors aim to adapt it to more complex terrain conditions.

The work of Hickey *et al.*, (1996; 2000), resulted in the production of an AML code (Arc Macro Langage), to calculate the LS factor. The digital input used is a DEM (digital elevation model). The code was rewritten in C++ programming language by Van Remortel *et al.*, 2004, in order to replace the old equations, with the new RUSLE algorithms (McCool *et al.*, 1989; 1997.). Our methodology consists to calculate the topographic factor LS through the executable AML C++ program (lsfac_c.exe), specially designed for this purpose.

LS = (λ/22,13) m 10.8*(Sinθ + 0.03) if the slope < 9%

LS = (λ/22,13) m16,8 *(Sinθ + 0,5) if the slope >= 9%

λ : Slope length θ: Slope inclination

m : slope length m, has been adopted over a wide range of slope gradients θ

Factors of vegetation cover (C), and anti-erosion practices (P)

Water and soil erosion is strongly controlled by vegetation cover. In the USLE/RUSLE, the action of vegetation is translated by the coefficient C. Thus anti-erosion agricultural practices are represented by the coefficient P.

The vegetation cover factor C, is one of the most important parameters in the USLE/RUSLE equation, it represents the relationship between bare soil erosion and erosion observed under a production system. It varies from 1 on bare ground to 1/1000th under forest, from 1/100th under meadows and cover crops, and from 1 to 9/10th under weeded crops. The C index is zero in conditions where the soil is totally non-erodible.

The P factor, represents the ratio between the land losses on a developed field and those of a nearby unmanaged plot of land or the wischmeier reference plot (ROOSE 1994). Anti-erosive practices mechanically limit the length of the slope and increase infiltration (isohypsis ploughing and ridging, benches, terraces and diversion ditches), they can help reduce erosion if vegetation is not very vigorous

In our study, only the type of vegetation cover and the recovery rate are taken into account to determine the values of the factor C, the anti-erosion practices observed on Google earth satellite images (Fig.2) were digitized and then integrated into the SIG Arc Gis.

The research carried out by Roose, (1994) in North and West Africa, Khatouri, (2003); Ait Brahim *et al.*, (2003); Sadiki *et al.*, (2004) and El-Garouani *et al.*, (2008) in Morocco and Masson, (1971) in Tunisia, was

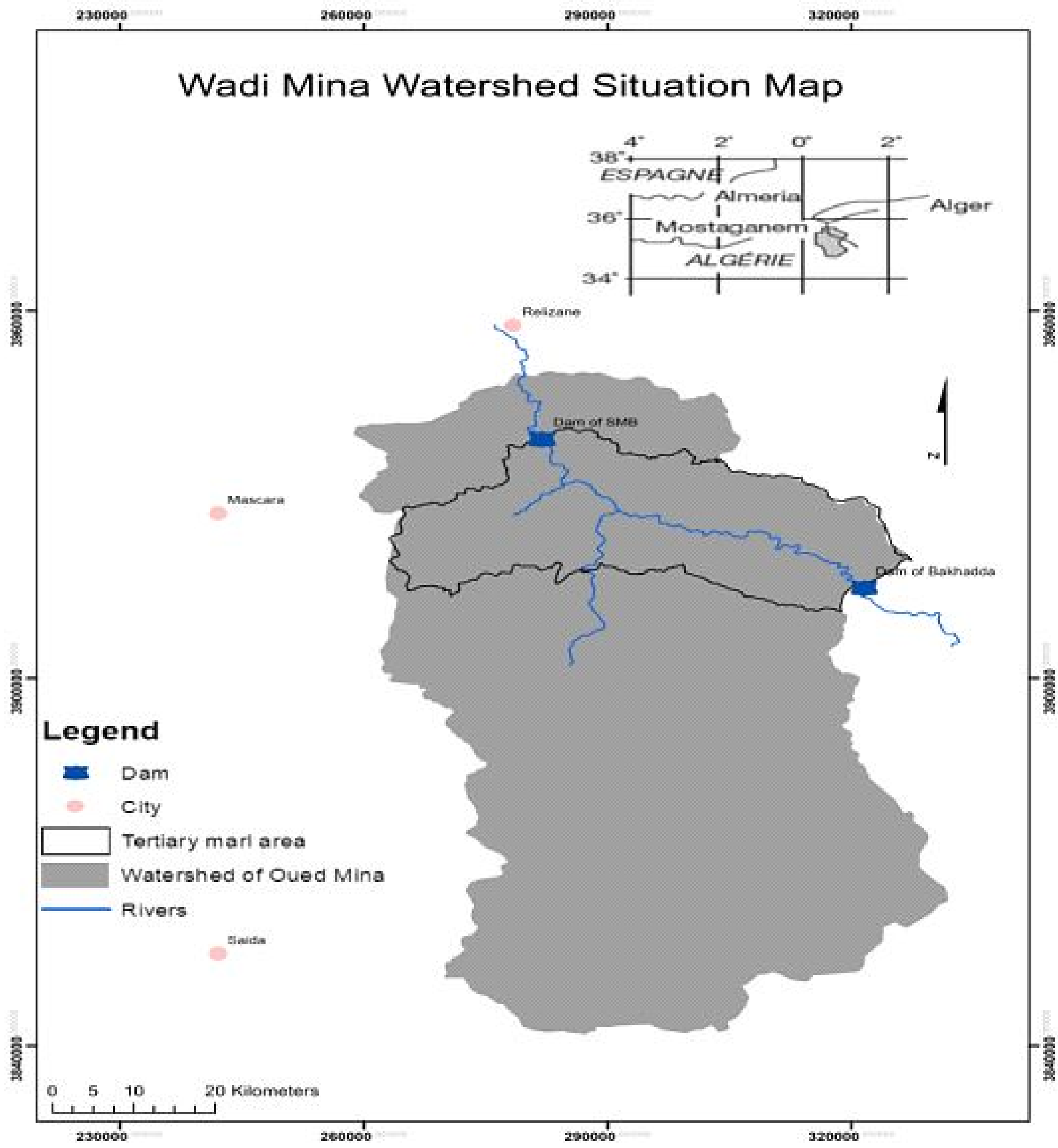


Fig.1: Localisation of Oued mina watershed.

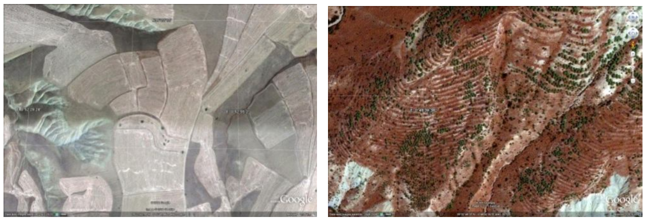


Fig. 2: Anti-erosive practices observed on Google earth.

used to attribute values for factors C and P (Tab.2 and 3).

Map crossing

The application of the universal equation of soil losses in the USLE, under its revised version RUSLE, allowed us to study separately the factors involved in water erosion, then proceed to cross-reference the various thematic maps obtained (factors R, K, LS, C and P) (Tab.1), using the Spatial Analyst - raster calculator module of the ARCGIS software. The crossing of the maps was done at a pixel scale of 24,379m.

Results and Discussion

Rainfall erosivity factor (R)

The R values obtained vary from 42 to 74, the lowest are observed around Sidi AEK Djilali and El-Hachem, the highest are located at the eastern limit of the study area at Mechraa-Sfaa. The annual average is 54.09 (Fig.4).

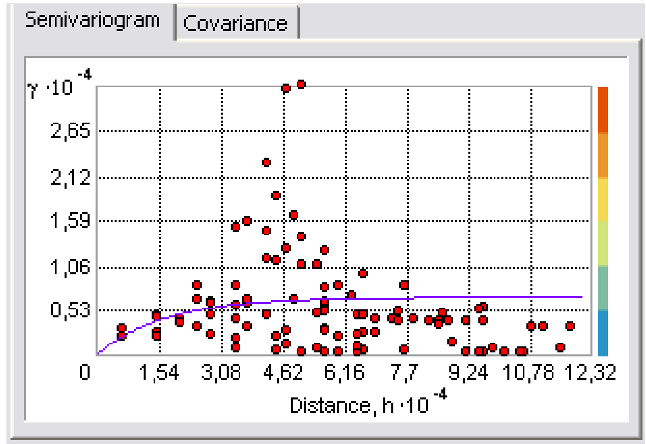


Fig. 2: Expotential model

Our values are relatively similar to those found by Gomer, (1994). The latter calculated by the wischmeier method, the R index on nine (09) stations distributed over the entire watershed of Oued Mina. The average R was 61 (N/h*a) for Ain Hamara, 50 (N/h*a) for EL-Hachem and 43 (N/h*a) for Sidi Mhamed-Benaouda. On the other hand, Touaibia, (2000) calculated an R index ranging from 12 to 40 (N/h*a in micro-watersheds north of Djilali Benamar. the average R factor is considered moderate to high, according to Gomer, 1994 it is rather moderate.

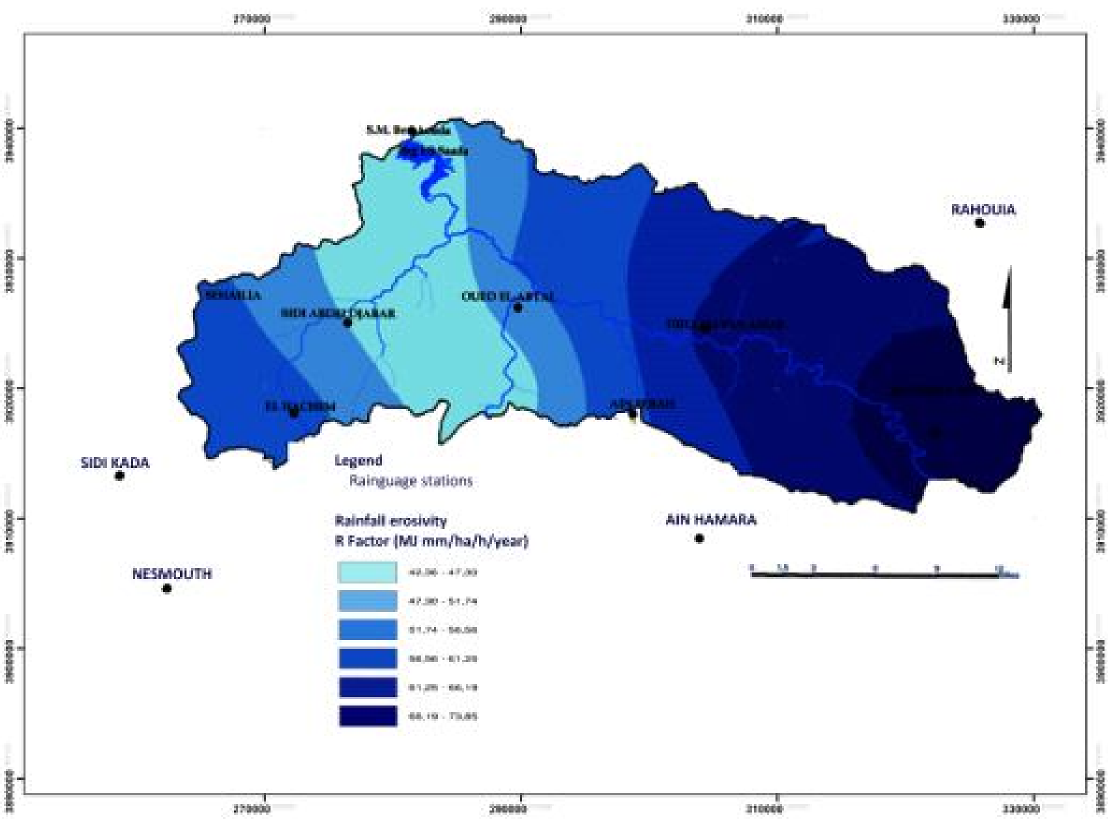


Fig. 4: Distribution of R factor.

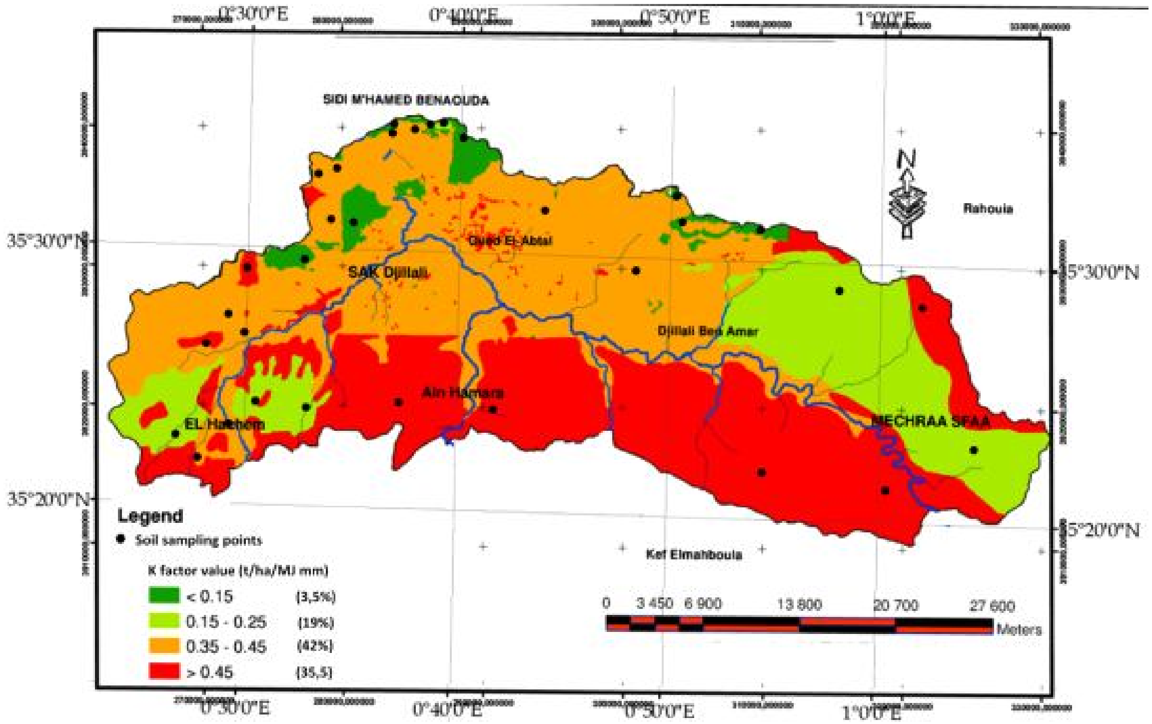


Fig. 5: Soil erodibilty factor (K).

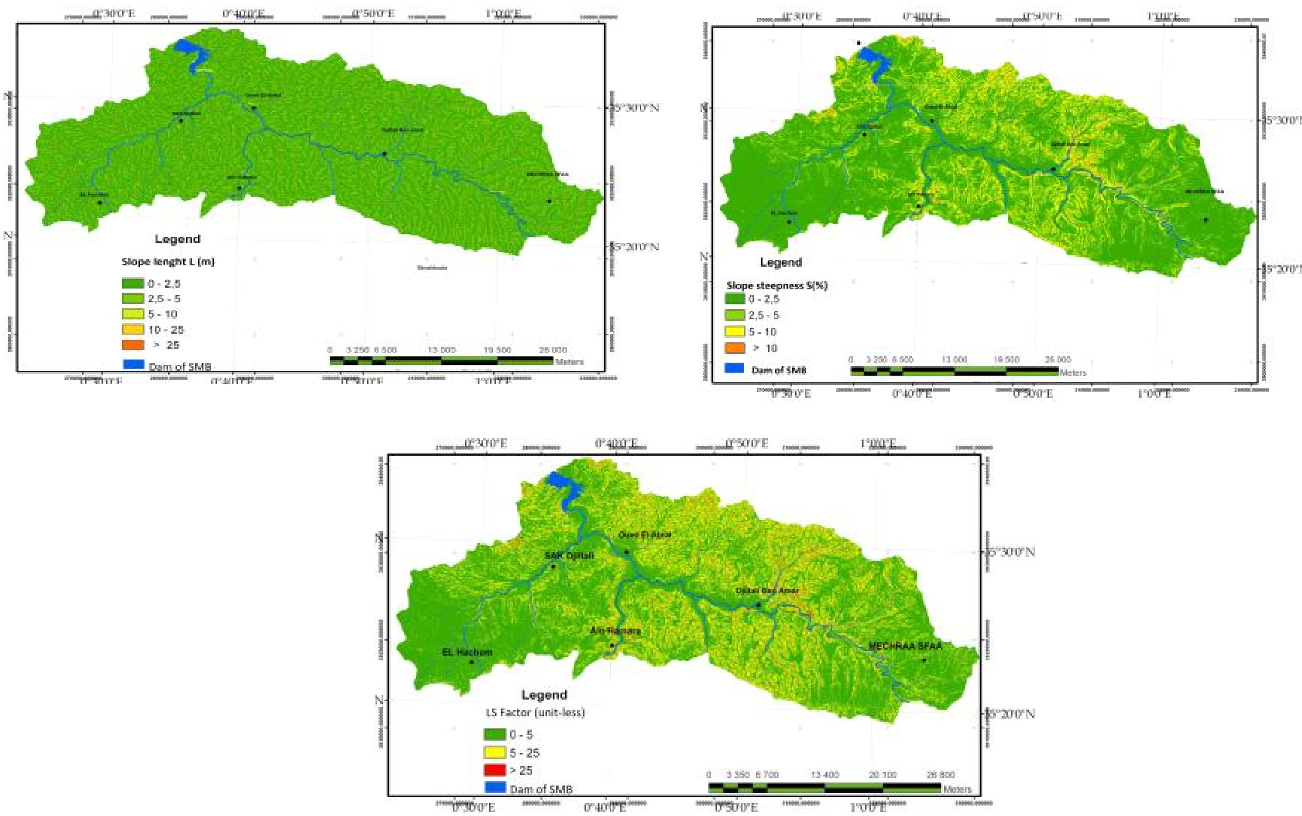


Fig. 6: A: slope length, B: slope steepness, C : LS factor.

Soil Erodibility factor (K)

The K-factor values range from 0.059 to 0.463 (Fig.5). Soils with silty and clayey silt texture are the most sensitive to water erosion. Islets of calcareous sandstone and coarse-textured unconsolidated deposits to the north and northeast have low values of K, 0.10 and 0.06 respectively.

Topographic factor (LS)

The results obtained show that L varies from 0 to

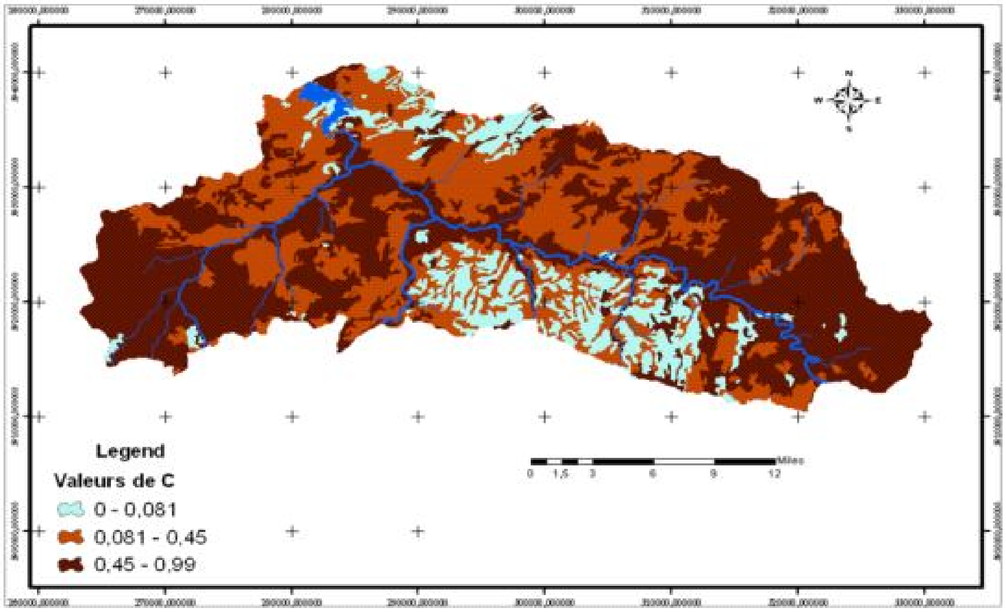


Fig. 7: Vegetation cover factor (C).

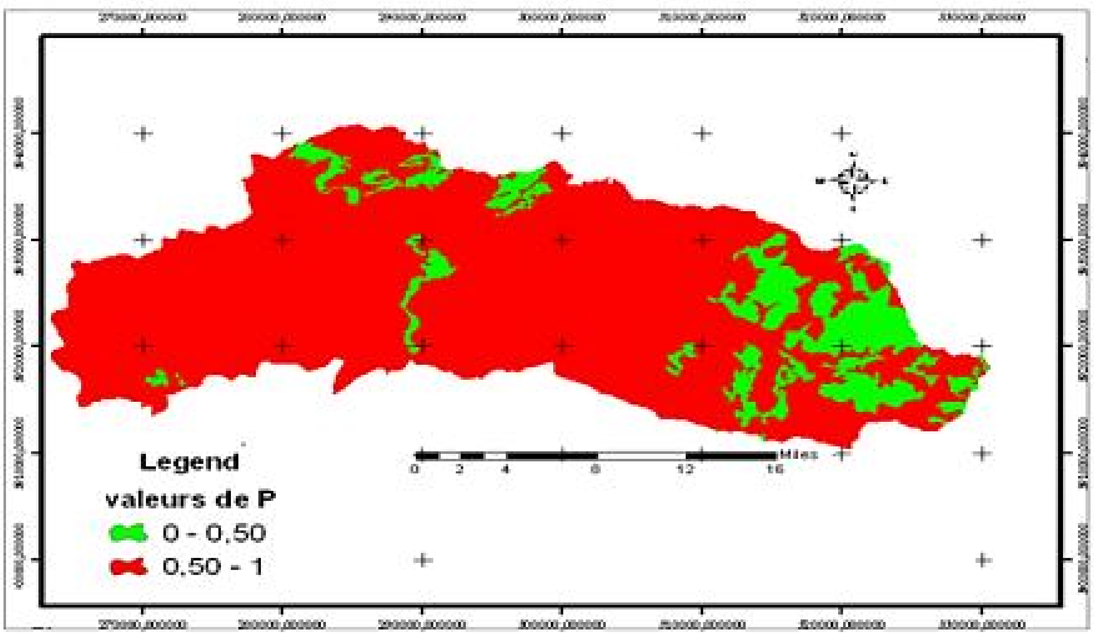


Fig. 8: Anti-erosive practices factor (P).

60.23 m with an average of 1.83 m. The class between 0 and 2.5m represents 76.8% (Fig.6). the slope inclination S varies between 0 and 26.76%, with an average of 2.14%. The class less than 2.5% occupies 69.62% of the total area, or 801 km2 (Fig.6).

The product of the two factors L and S, varies from 0 to 150,04; with a remarkable dominance of values below 5. The average is 2.26 (Fig.6).

The maps obtained show that the LS factor is much more sensitive to variations in the slope inclination S. According to Renard *et al.*, (2011), a 10% error in the calculation of the L factor gives a 5% error in the soil losses calculated. This value can reach 20%, with a 10% error in the S factor (Renard *et al.*, 2011).

Factors of vegetation cover (C), and anti-erosion practices (P)

Agricultural areas occupy about half of the study area, with matorral accounting for 27% of the total area, followed by degraded bare soils everywhere, which total about 10%. The maquis - garrigue formations total 9% and are particularly intertwined with the matorral. Thus, more than 50% of the area studied has a coefficient C

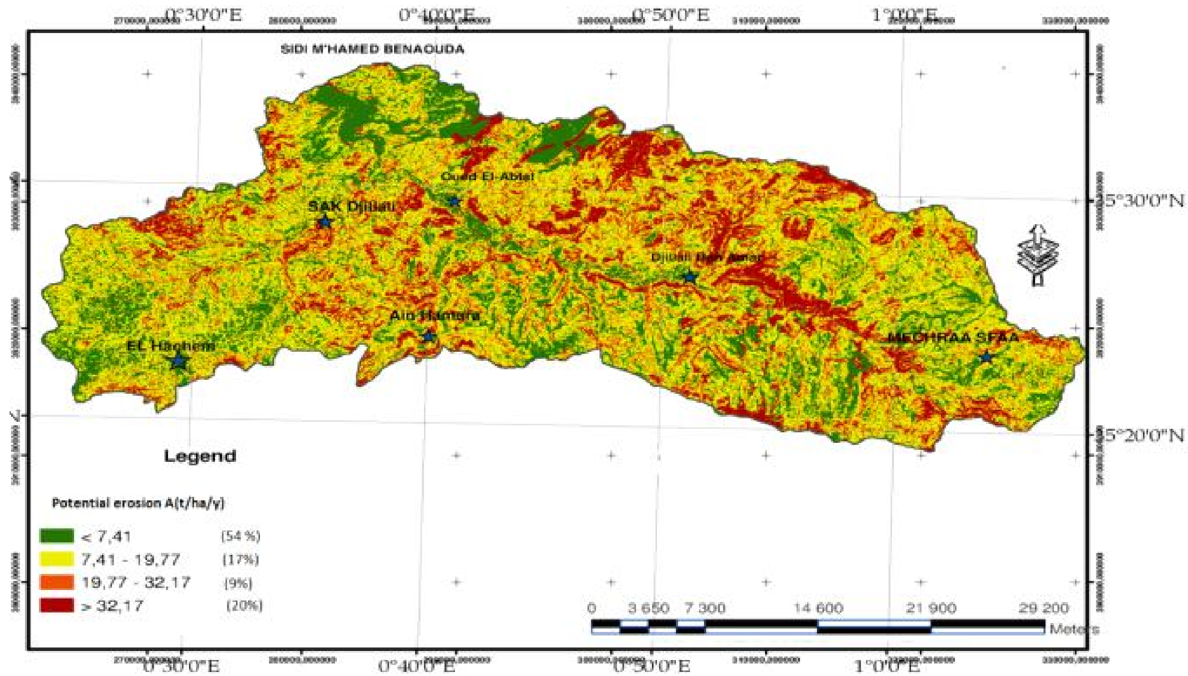


Fig. 9: Erosion risk in the tertiary marl area according to RUSLE.

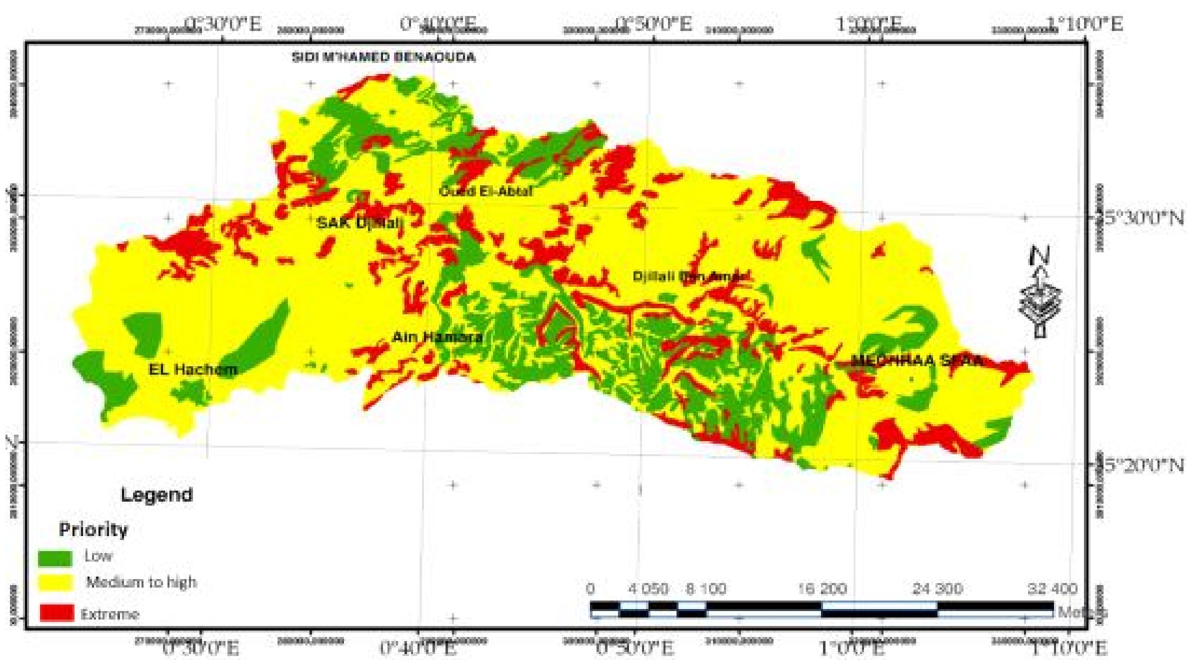


Fig. 10: Priority area for anti-erosion treatments.

and higher than 0.45 (Fig.7).

Two antierosive practices were observed in the tertiary marl area, namely ploughing in the direction of the contour lines, and planting on small terraces over an area not exceeding 30% of the study area. P is greater than 0.5 over more than 60% of the study area (Fig.8), This is due to the lack of know-how of farmers in soil conservation, through field trips we have identified practices promoting water erosion, namely tillage in the direction of the slope.

Spatial distribution of soil losses

The results we obtained show that 54% of the marl area has an erosion rate of less than 7.41 t/ha/year. Critical values above 20 T/ha/year are not negligible, they occupy more than a quarter of the total surface area, or 28.37%, and are distributed over degraded and gullied lands (Fig.9). The annual average for the entire study area is estimated at 15,107 t/ha/year.

Our results are clearly similar to those measured on the experimental plots in the Taasalet area, by kouri,

Table 1: Summary of the methodology used.

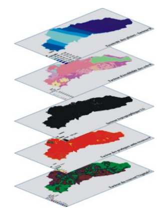
USLE Factor	Data	Map crossing	Erosion rate (t /ha/year)
R	Pluviometric data		K * R * L * S * C * P
K	Physical characteristics of soil		
LS	A DEM 24 m of resolution Program lsfac_c.exe		
C	Vegetation cover map		
P	Digitization from google earthField trips		

Table 2: Factor C values.

Vegetable cover	C_RUSLE
Grassland pasture path	0.13
Matorral	0.18
Bare soil	0,9
Open scrubland maquis	0.15
Fallow land	0,9
Reforestation and forest	0,04
Field crops	0,7

Table 3: Factor P values.

Soil utilisation	P
Bare soil degraded	1
Fallow land	1
Terrace and terrace plantation	0,14
Low-density forest plantation	0,5
Tillage in level curves	0,2
Market gardener	0,5
Arboriculture	0,5

Table 4: Anti-erosion practices proposed according to the degree of water erosion.

Water erosion rate	Mechanical measurements				Biological measurements				
	Torrential correction with thresholds	Stone cords	Collinar retention	Land improvement	Reforestation	Live hedges	Re-vegetation	Opuntia plantation	Fruit plantation
< 7,41 T/Ha/an				•		•	•	•	
7,41 à 19,77 T/Ha/an		•	•	•	•	•	•	•	•
19,77 à 32,17 T/Ha/an	•	•	•		•		•	•	•
>32, 17 T/Ha/an	•				•		•	•	•

NB: the colors in the table correspond to the priority planning classes. See image 61.

(1993) Gomer, (1994) and Touaibia, (2000). The annual average for the entire marl area is estimated at 25,457 t/ha/year. Solid transport measurements were carried out throughout the Oued Mina watershed by Touiaibia and Achite, (2003). The results obtained also showed that the marl area is heavily affected by water erosion with an average of more than 20 t/ha/year.

The effect of vegetation cover is clearly noticeable in classes with low to moderate erosion. As a result, the intensity of erosion and the quantities of sediment produced vary mainly according to current land use and the nature of the land and its slope. Management practice priorities will be based on the risk of soil erosion, and sediment transport downstream of the Oued Mina watershed.

Development proposals

The soil loss map obtained made it possible to locate the priority areas for treatment (Fig.10), and to propose anti-erosion measures table 4 that were considered useful, necessary or indispensable in order to reduce soil loss and siltation rates in the study area.

The measures proposed in our study have been divided into two types, mechanical and biological table 4 the combination between the two modes of intervention depends on the rate of erosion. Classes with soil losses greater than 7 T/Ha/year and less than 32 T/Ha/year are grouped into a single box (medium priority a high), These classes should have a particular intention to avoid any form of gully and badlands. Areas with soil losses of less than 7 T/Ha/year are not a priority for intervention, but require good management of water and soil resources through appropriate erosion control practices.

The aim of purely mechanical structures is firstly to reduce the slope and therefore the flow velocity along the talwegs. However, they are only effective temporarily and therefore require biological fixation inside the gullies.

From a social point of view, the participatory approach is an essential component that must not be neglected in order to guarantee the effectiveness of any development or restoration programme.

Conclusion

The mapping approach is a powerful tool for evaluating water erosion in each pixel of a studied area. The application of the universal equation of soil loss using an ARCGIS geographical information system highlights generally modest soil losses on the interflows of the marl area, but also critical on bare ground that requires development. Thus, on the land occupied by field crops in the West and East, erosion is moderate to strong, we have also noticed the beginning of ravine development, which is probably due to agricultural practices that favour erosion.

The RUSLE model can evaluate pixel erosion on more complex relief terrain (LS factor), hence the advantage of the modifications made to the USLE model which was initially limited to the assessment of sheet erosion. Comparison of the results obtained with those measured in the field in the experimental plots shows the importance of applying this methodology in assessing erosion rates, as well as a decision-making tool in watershed management and erosion control projects.

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