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# Assessment of soil water erosion using RUSLE and GIS techniques: a case study of Oued El-Abtal watershed, Algeria

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**Key words:** Watershed, Oued El-Abtal, Water erosion, GIS, RUSLE model.

**Abstract**

Water erosion is considered as the principal cause of agricultural land exhaustion and landscape remodeling, it is also a cause of siltation of hydraulic structures and loss of their capacity. The Oued El-Abtal watershed in Algeria is highly exposed to this phenomenon due to several factors such as the degradation of vegetation cover, irregular stormy rains, and inappropriate land use. To quantify the current water erosion rate in this area, we used the application of the revised RUSLE universal soil loss equation in an interactive manner with the SIG. The approach adopted consists to calculate and spatialize the main factors involved in water erosion constituting the RUSLE model, rainfall erosion (R), soil erodibility (K), topographic factor (LS), vegetation cover (C) and anti-erosion practices (P), the thematic maps obtained were crossed using the Spatial Analyst module of the ARCGIS SIG to produce the global map of the erosion potential. The average erosion rate in the study area is 11 T/Ha/year. The results obtained show that erosion intensity and sediment production quantities vary mainly depending on current land use, nature of land and its slope.

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## Introduction

Soil water erosion is a widespread and generally irreversible phenomenon. Its complexity is manifested by a regional diversity of factors that limit or favour it. Its disastrous and spectacular consequences offer a bare and furrowed landscape. In northern Algeria, this phenomenon has accelerated following the clearing of forests and scrubland, with serious consequences for the conservation management of water and soil resources (Demmak, 1982,; Touaibia, 2000; Mazour et Roose, 2002; Achite *et al.,* 2006; Boutkhil *et al.,* 2013). The Ouadi El-Abtal watershed is a typical example. Erosive processes threaten the early siltation at Es-Saada dam, this last one destined for the drinking water supply of Relizane city and the irrigation of Mina plain. According to the studies carried out in this area, which was the subject of our work, there was significant soil heterogeneity, very scattered or non-existent vegetation cover and poorly distributed rainfall both in space and time (GTZ, 1996; TECSULT, 2006; Kouri, 2010; Benchettouh, 2012; Neggaz, 2012; Toumi, 2013).

In the aim to study the phenomenon of water erosion, several researchers (Kouri, 1993; Kouri *et al.,* 1997; Gomer, 1994; Touaibia, 2000; Touaibia et Achit, 2003; Touaibia *et al.,* 1992; Touaibia *et al.,* 1999) have carried out rain simulation work at many points in and around to our study area. However, interpolation of results at the regional scale remained difficult to achieve, climate variation requires more than 10 years of data to obtain an accurate annual average of soil losses and direct measurements at many points in a region are impractical. Currently, the development of geographic information management has allowed the spatialization of a point model for soil loss assessment, the universal equation of USLE soil losses of Wichemier and Smith 1958, the USLE is used in its revised version RUSLE In interaction with SIG around the world for modelling and risk assessment of water erosion (Markhi *et al.,* 2015; Khali Issa *et al.,* 2016; EL-Hafid *et al.,* 2018). Its application varies according to the objectives, means and scales of work.

The RUSLE model 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 GIS algorithms. In interaction with the GIS, it makes it possible, in part, to quantify annual soil losses and, in other part, to identify and map the soil surfaces that require intervention.

The experimental approach adopted here consists to evaluate the annual average soil losses in Oued El-Abtal watershed, by spatializing the universal equation of soil losses, under its revised version RUSLE. The calculations required mapping and analysis of the main factors involved in water erosion, namely: rainfall aggressiveness, soil erodibility, terrain topography (inclination and slope length), vegetation cover and erosion control practices, which made it possible to assess the amount of soil that could be removed annually for each pixel in the study area.

## Materials and methods

*Presentation of the site*

Located in the northwest of Algeria, Oued El-Abtal watershed covers an area of about 698 km2 (Fig. 2), and is characterized by a semi-arid climate and irregular and torrential rainfall that varies from 230 to 400 mm/year. With an average of 320 mm/year. The hydrographic network is dense and branched with temporary rivers with seasonal flow regimes and discharge into Oued Mina (Touaibia and Achite, 2003). The relief is very fragmented, despite the larger area of land on low slopes that does not exceed 10% over more than 45% of the basin's surface area (average 10.27%, minimum 0%, maximum 101.30%). The average altitude is 484 m with a minimum of 133 m and a maximum of 1,117 m. The gully is denser in the north, and the deep V-shaped cuts are generally steeper in the south than in the north. Geology mainly includes marl formations. In terms of land use, degraded matorral and bare soils account for more than 45% of the total area (Fig. 1).

*Assessment of water erosion rate*

*Adaptation of Universal Soil Loss Equation (USLE)*

The RUSLE (Revised Universal Soil Loss Equation) model is a modified version of the Universal Soil Loss Equation (USLE) originally developed by Wischmeier and Smith, 1978. According to the USLE, erosion is a multiplicative function of rainfall erosion (factor R), that multiplies the resistance of the environment, which includes K (Soil Erodibility), LS (Topographic Factor), C (Vegetation Cover) and P (Anti-Erosive Practices) (Erosion Rate t /ha/year = K * R * L * S * C * P). The revised equation 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 the algorithms associated with GIS.

*Methodological approach*

The RUSLE model has been integrated under a geographic information system to enable exhaustive modelling and mapping of the erosive phenomenon. The work methodology consists to integrate and represent cartographic and descriptive information on the different factors and parameters of erosion in a geographic information systems platform. A spatial reference database containing all quantitative information concerning the study area has been created (Fig. 3). The empirically based quantitative erosion model thus makes it possible to provide an estimate of soil losses, in T/ha/year, per unit area, which corresponds, in the case of SIG mapping overlay, to the base pixel of the MNT.

*Rain erosion factor (R)*

The original erosion index, proposed by Wishmeier and Smith in 1958, was estimated on the basis of observations linking land losses and the product of Ecinet kinetic energy and the maximum rainfall intensity of 30 minutes[$mmh^{-1}$] (R = Ecin i30). The inconvenient of this index is the unavailability of rainfall data, in particular the intensity of rainfall at 30 minutes i30 at our meteorological stations; To compensate for the lack of data, several researchers (Kalman, 1967; Fournier, 1960; Arnoldus, 1980; Rango and Arnoldus, 1987) have developed alternative formulas that only require monthly and annual rainfall. The formula of Rango and Arnoldus (1987), used by several researchers in North Africa (Sadiki *et al.,* 2004; Elkhatouri, 2003; El-Bouqdaoui *et al.,* 2006; Chen *et al.,* 2008; Meddi, 2013; Kouadri *et al.,* 2016; Modeste *et al.,* 2016) was applied in our study, in Eleven (11) meteorological stations distributed within and around the study area (Fig. 2). The database is spread over a period of 20 years.

$$\text{Log } R = 1.74 \text{ Log} \sum (Pi^2/P) + 1.29$$ (Rango et Anoldus, 1987)

(- Pi: monthly precipitation - P: annual precipitation in mm.)

The interpolation of the R factor on the entire study area is performed according to the principle of ordinary krigéage, a geostatistical method increasingly applied around the world (Deveughele and Rizzoli, 1997; Goovarerts, 2000; Mortier, 2007; Arnaud *et al.,* 2000; Batti, 2005; Baillargeon, 2005). The geostatistical Analyst extension of ARC GIS was used to establish the distribution map of the climatic aggressivity factor R.

*Soil erodibility factor (K)*

The erodibility of soils K, expresses the cohesion and resistance of the soil against erosion. A multitude of experiments on different types of soil, allowed Wischmeier *et al* 1978, to develop an operational equation, based on four parameters, the rate of organic matter, soil texture, structure and permeability.

$$100K = 2{,}1\ M^{1{,}14} * 10^{-4}(12-a) + 3{,}25(b-2) + 2{,}5(c-3)$$

K: soil erodibility factor.

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

A: organic matter content.

S: soil structure code

P: permeability code

To determine the values of the K factor in the study area, Soil analyses of forty-three (43) samples selected from the map of lithological units were used (Fig. 7). 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*

Practically all models for erosion and soil loss calculation include the topographic factor, under certain forms. The Wischmeier formula defines the factor LS, as the product of the slope length L, and its inclination S, per unit area, which is the standard plot length of 22.1m and a slope of 9%. The use of USLE at the regional scale has been limited by the inability to produce reliable estimates of the topographic factor LS (Hickey *et al.,* 1994, Van Remort *el al.,* 2004; Zhang, 2013 & 2017). Errors of 10% were found in the estimation of soil losses by McCool *et al.* (1987).

The work of Hickey *et al.,* 1994 and 2000, resulted in the production of an AML code (Arc Macro Language), which is usable in the SIG IDRISSI and ArcInfoTM, to calculate the topographic factor LS. The numerical input used is a Digital Elevation Model (DEM). The Hickey method was designed to calculate the slope length, as it incorporates a variable of "slope-off", which enhances the detection of the beginning and end of each slope length (λ) (José *et al.,* 2010). 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. Some changes associated with specific points, such as flat areas, tracks and other specific slope inclination criteria have been added, to obtain a new executable C++ AML code (lsfac_c.exe). This last one was used in our study to determine the topographic factor LS with the following formulas of Mc Cool *et al.* (1989):

$LS = L*S$

$L = (\lambda / 22{,}13)^{m}$

$M = \beta / (1+\beta)$

$\beta = (\sin\theta)/[3*(\sin\theta)0{,}8 + 0{,}56]$

$S= 10{,}8*\sin S\theta+0{,}03$

$\theta = 10{,}8 * \sin\theta - 0{,}5 \quad \theta \leq 9\%$

Where : λ is le length of the slope ; m is a variable length-slope exponent ; β is a factor that varies with slope gradient ; θ slope angle.

*Vegetation cover factor C*

Water erosion of soils is strongly controlled by vegetation cover. In the USLE/RUSLE model, vegetation action is translated by the coefficient C which represents the ratio between erosion on bare soil and erosion observed under a production system. It varies from 1 on bare land to 1/1000th under forest, from 1/100th under meadows and cover plants, and from 1 to 9/10th under weeding crops. C is zero in conditions where the soil is totally not erodable. In our study, the type of vegetation cover and the recovery rate are taken into account to determine the values of factor C. The use of the land cover map and satellite images, also 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 1964 in Tunisia, were used to determine the values of factor C.

*Anti-erosion practices factor P*

The P factor takes into account purely anti-erosion practices such as tillage and level-curve crops in alternating bands or terraces, ridging, or ridging in level-curves, and bench reforestation. It varies from 1 on bare soil without any anti-erosion measures to about 1/10th when partitioned ridging is used on a gentle slope.

*Crossing of maps*

The RUSLE equation was solved by superposing, with the use of GIS, the different thematic maps relevant to each of the factors, namely, R, K, LS, C and P. The database conveyed by each layer was adapted by attributing a precise value to the factor concerned based on the thematic content of the map polygon. For example, a particular value of the C factor was defined for each polygon based on the type of vegetation cover as a discriminatory element. All combinations were performed in "Raster" mode using the "Map Calculator" tool of the "Spatial Analyst" module while applying the mathematical equation of the USLE model of Wischmeier & Smith (1978), this makes it possible to evaluate the erosion rate at all points in the study area and to develop the synthetic soil loss map according to the methodological flowchart (Fig. 3) The resultant values give the soil loss in tons per hectare per year at the pixel scale.

**Results and discussion**

*Rainfall erosivity*

The values of the rainfall erosion index R varied from 40.84 to 63.85, the lowest values were observed around Sidi M'Hamed Benaouda, and Sidi Abdelkader in the north, the highest values were located in the south of the study area at Nesmoth (Fig. 4). The annual average is 54. More than half of the study area had a climatic aggressiveness greater than 50. Our values are relatively similar to those found by Gomer 1994, who calculated by the wischmeier method, the R index on nine (09) stations distributed over the entire watershed.

**Tab 1.** C and P factor values.

| Vegetable cover | C_RUSLE | Soil utilisation | P |
|---|---|---|---|
| Grassland pasture path | 0.13 | Bare soil degraded | 1 |
| Matorral | 0.18 | Fallow land | 1 |
| Bare soil | 0,9 | Terrace and terrace plantation | 0,14 |
| Open scrubland maquis | 0.15 | Low-density forest plantation | 0,5 |
| Fallow land | 0,9 | Tillage in level curves | 0,2 |
| Reforestation and forest | 0,04 | Market gardener | 0,5 |
| Field crops | 0,7 | Arboriculture | 0,5 |

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 M'hamed Benaouda. On the other hand, Touaibia (2000) calculated an R index varying between 12 and 40 (N/h*a) in micro-watersheds located in the north of Djilali Benamar. In our study area, the average R factor is considered moderate (Gomer, 1994).

**Fig. 1.** Sidi M'hamed Benaouda Dam and landscape in the study area.

*Soil Erodibility Factor K*

In the watershed of Ouadi El abtal, the K factor varies between 0.13 and 0.65 t ha/MJ mm, and between 0.20 and 0.40 t ha/MJ mm over more than 70% of the total area of the study area (Fig. 7), this shows a clear fragility of the soils and their susceptibility to erosion. These results are explained by the dominant silty to silty clayey texture in the study area.

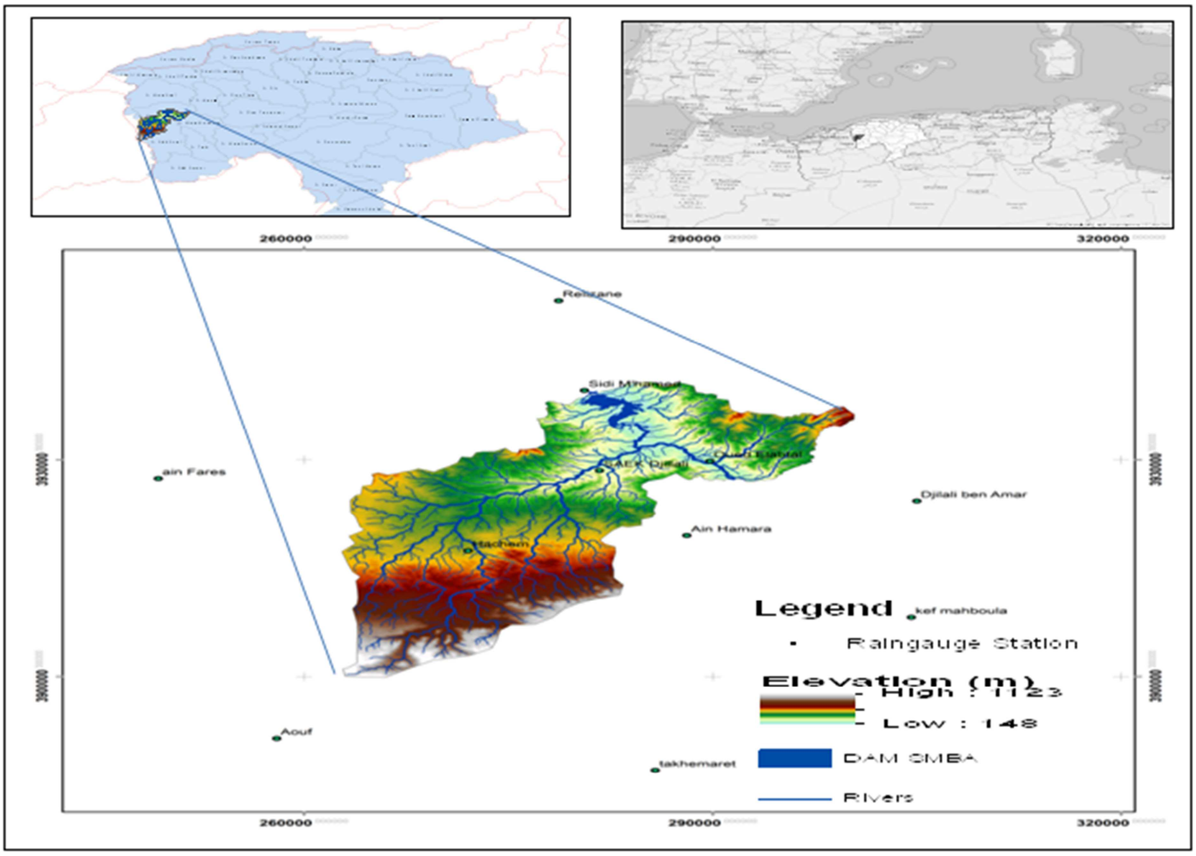


**Fig. 2.** Localisation of Oued El-Abtal watershed.

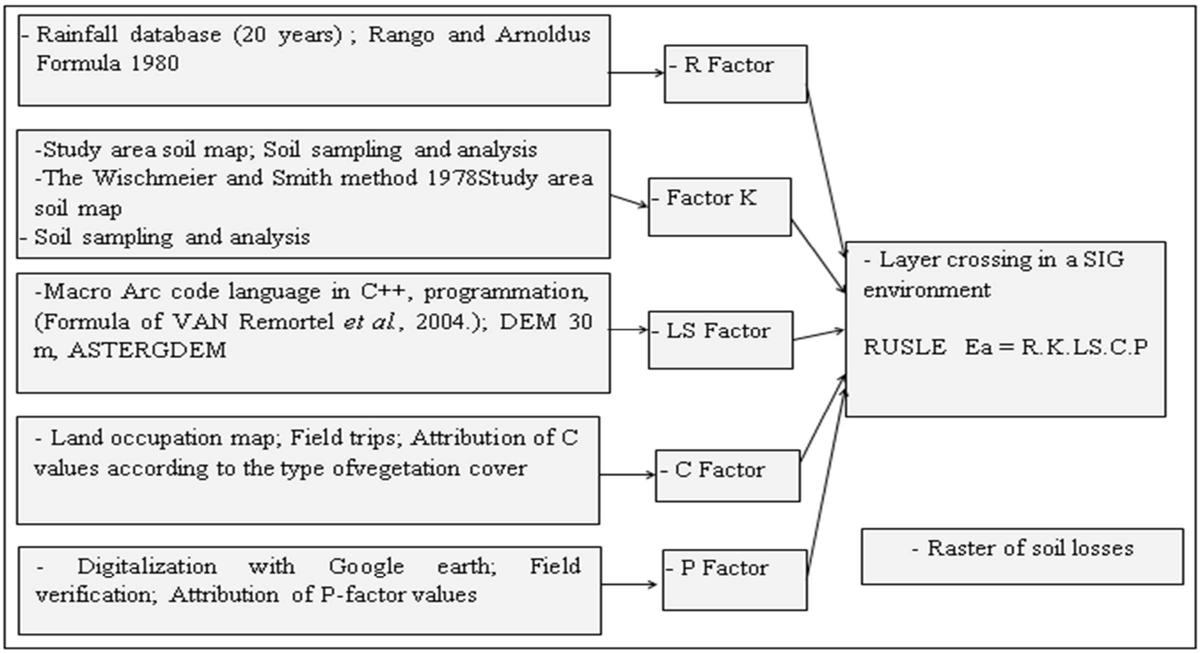


**Fig. 3.** Methodological approach.

USDA classifies soils with high silt content as the most sensitive to erosion because they detach easily and tend to form scabs that promote runoff. Richter and Negendank (1977) showed that soils with 40 to 60% silt are the most sensitive to erosion.

*Topographic factor LS*

The modifications made to the L factor calculations have the advantage to use the longest flow path as an estimate of slope length, which permits to introduce the cumulative effect of runoff into the RUSLE equation.

The use of the AML code written by Hicky *et al.*, 2001 and 2004 also permits the detection of slope ruptures (Fig. 8A). In the Oued El-Abtal watershed, no work has been resumed on this factor. Our calculations show that L varies from 0 to 6.24 m with an average of 1.12 m.

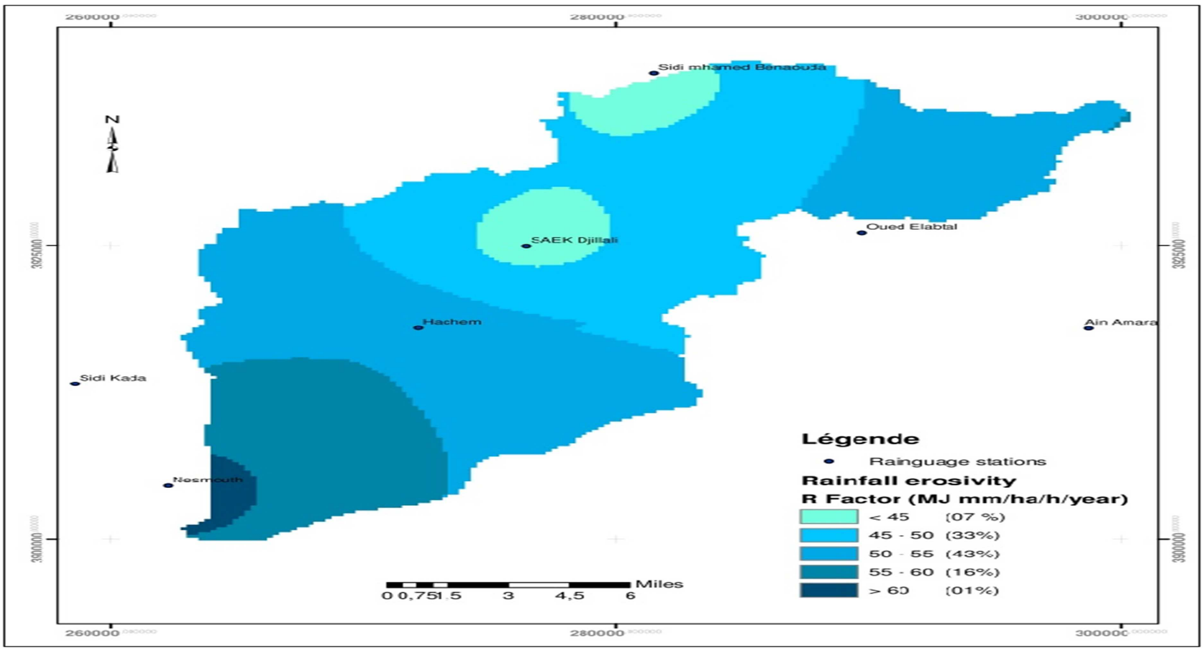


**Fig. 4.** Distribution of R factor.

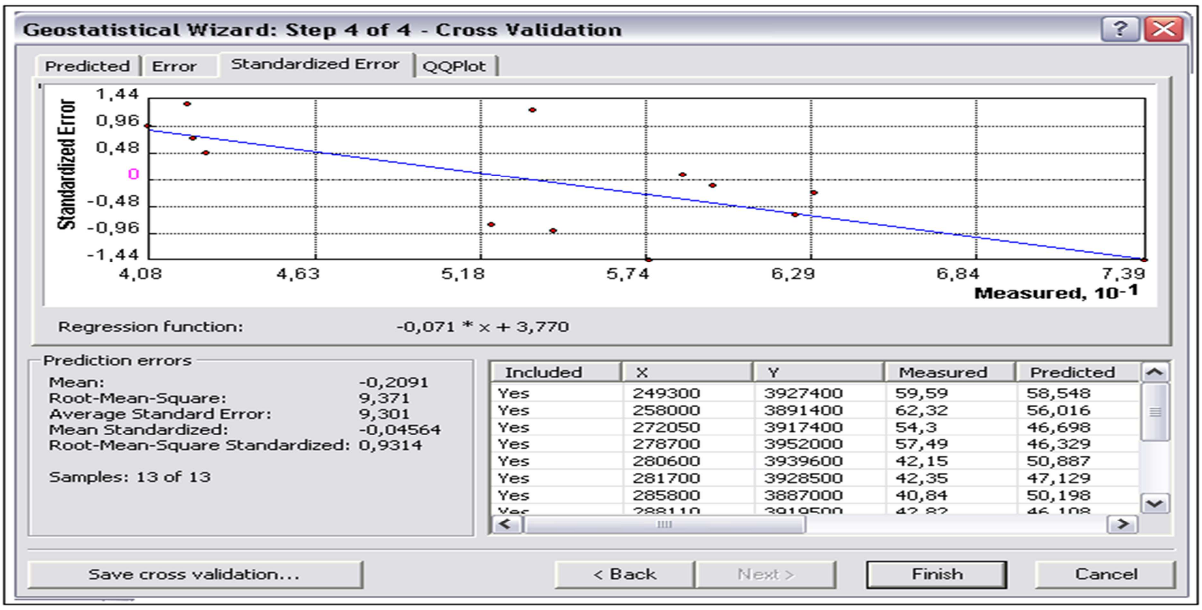


**Fig. 5.** Cross validation of type error.

The slope inclination S, varies between 0.05 and 14.85%, with an average of 2.04%. The class less than 2.5% covers 69.62% of the study area (Fig. 8 B).

On the other hand, those above 10% represent only 1.01%. This could be explained by a study area topography where the slopes are less than 10% over half of the total area.

The product of both length and inclination of slope LS, does not exceed 5% over 70% of the total area of the study area (Fig. 8C). They occasionally exceed 10% on steep slopes. The comparison of obtained maps indicates that LS factor is much more sensitive to changes in S factor. According to Renard *et al.,* (2011), soil loss calculations are often less sensitive to slope length than to other USLE/RUSLE factors. A 10% error in the results of the factor L gives a 5% error in the soil losses calculated.

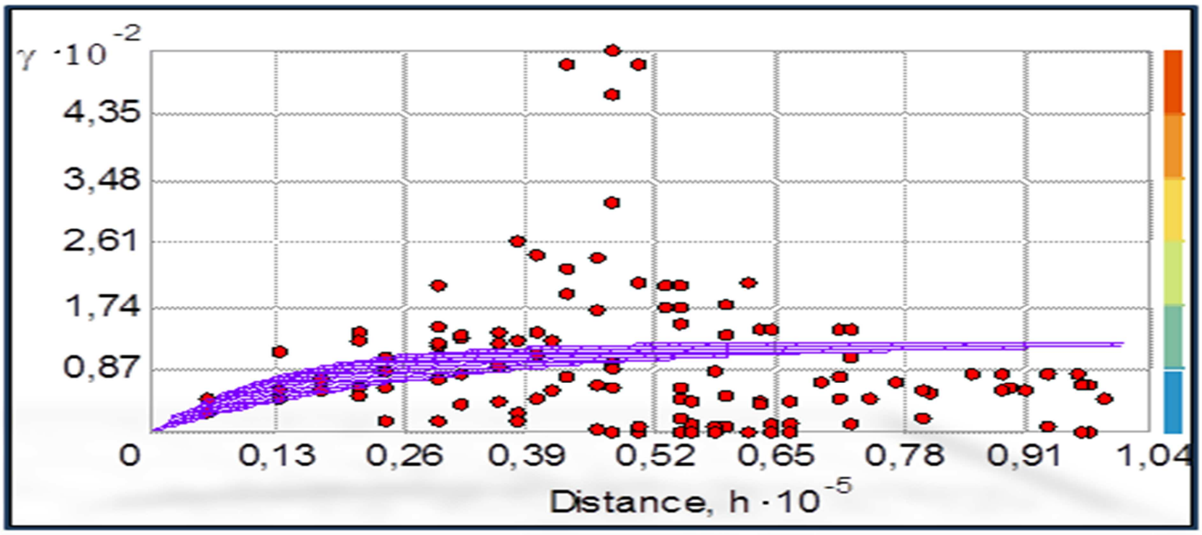


**Fig. 6.** Exponential model.

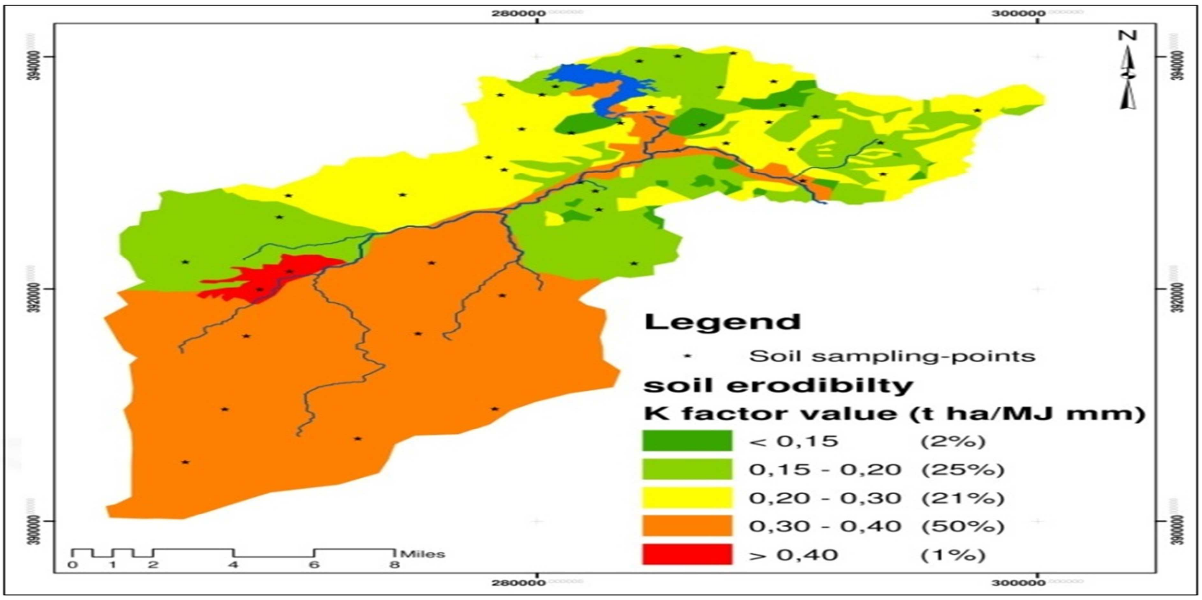


**Fig. 7.** Soil erodibility factor (K).

This value can reach 20%, with a 10% error in the S factor. On the other hand, the soil loss is much more sensitive to variations in slope inclination than in its length.

*Vegetable cover and Anti-erosive practices*

The C factor varies from 0.04 to 0.9 (Table 1), Annual crops (cereals and legumes) occupy nearly 34% of the area, bare soils very sensitive to runoff and erosion occupy 11%. This gives C values between 0.7 and 0.9 over 45% of the area where temporary and discontinuous cover does not effectively protect the soil (Fig 9). Concerning the factor P, apart from the terraces and terrace plantations to the north of the study area, no other form of erosion control practices were observed (P=1 over 50% of the basin).

The tillage is not always done in the direction of the contour lines. The attribution of P factor values (Table 1) is based on the work of ROOSE (1977) Wischmeier & Smith, (1978).

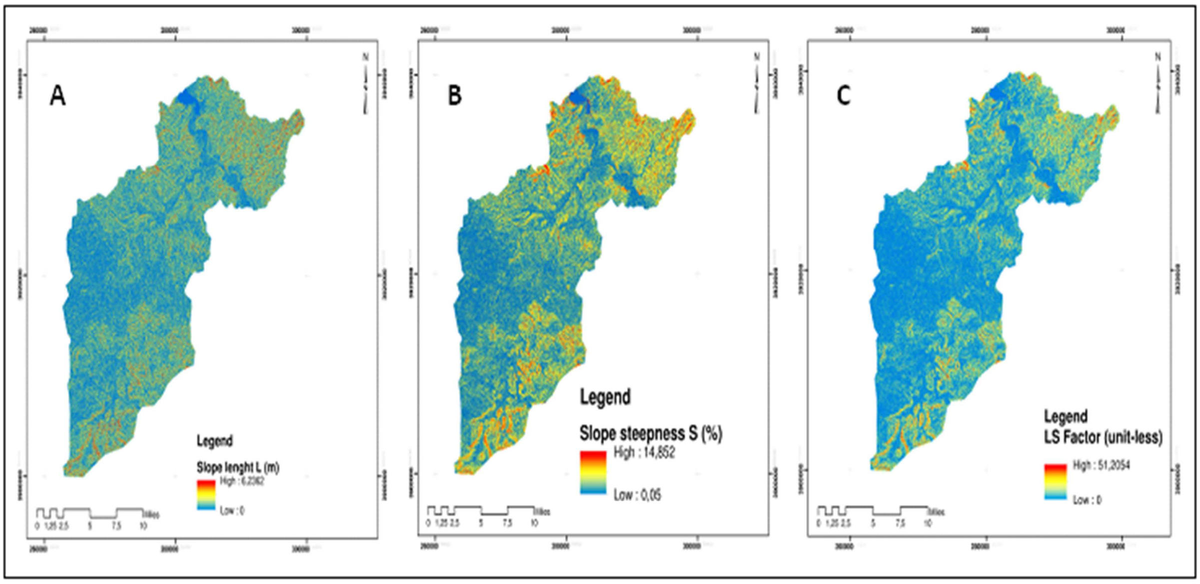


**Fig. 8.** A: slope length, B : slope steepness, C : LS factor.

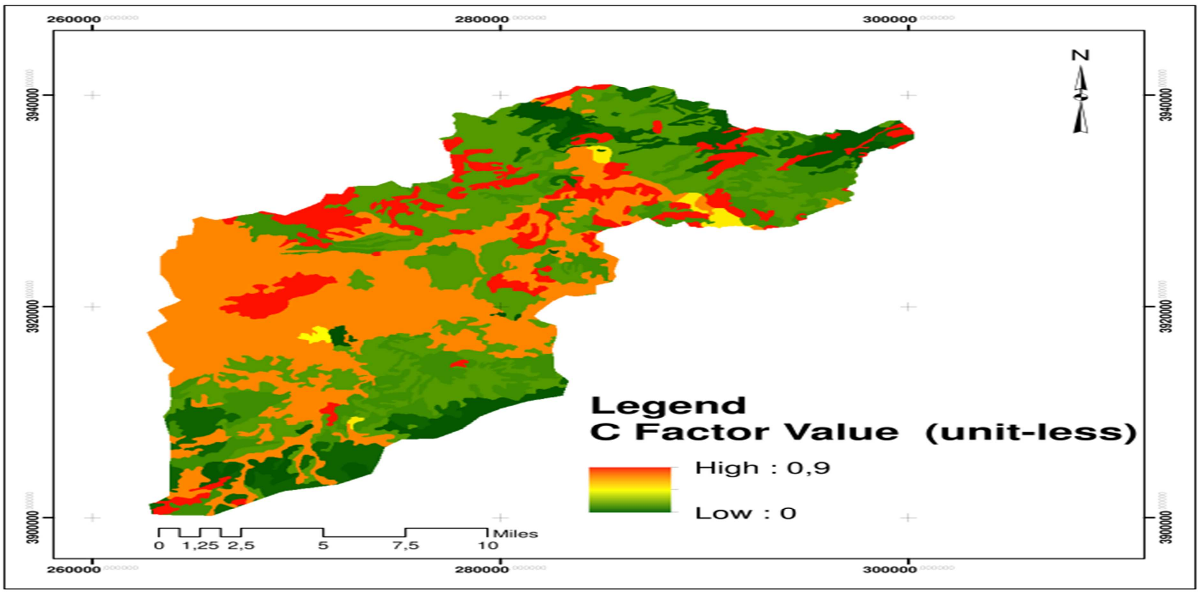


**Fig. 9.** Vegetation cover factor C.

*Spatial distribution of soil losses*

The approach followed permitted to study separately the factors involved in water erosion, then to cross-reference the various thematic maps obtained (factors R, K, LS, C and P) using the Spatial Analyst module (raster calculator) of the ARCGIS software. The soil loss classes are distributed according to the principle of soil loss tolerance, used in the United States (fig 11). Erosion rates below 7.41 t/ha/year remain tolerable and allow high agricultural production, however, values above 20 t/ha/year indicate that the soil is degraded and that development is required. The results we obtained show that soil losses are generally modest on the interferences of the basin, but also critical on bare soil. Thus, on land occupied by field crops, erosion is medium to high, with the beginning of gully development due to agricultural practices that promote erosion (Fig 12).

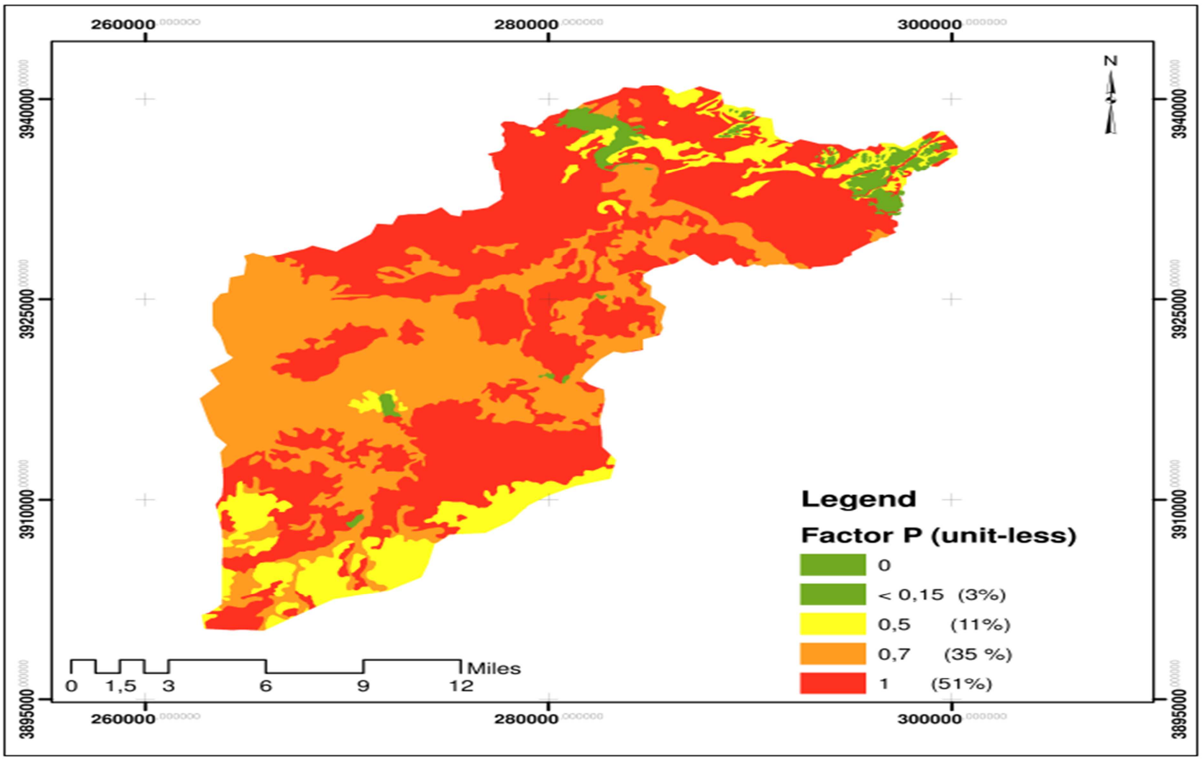


**Fig. 10.** Anti-erosive practices factor P.

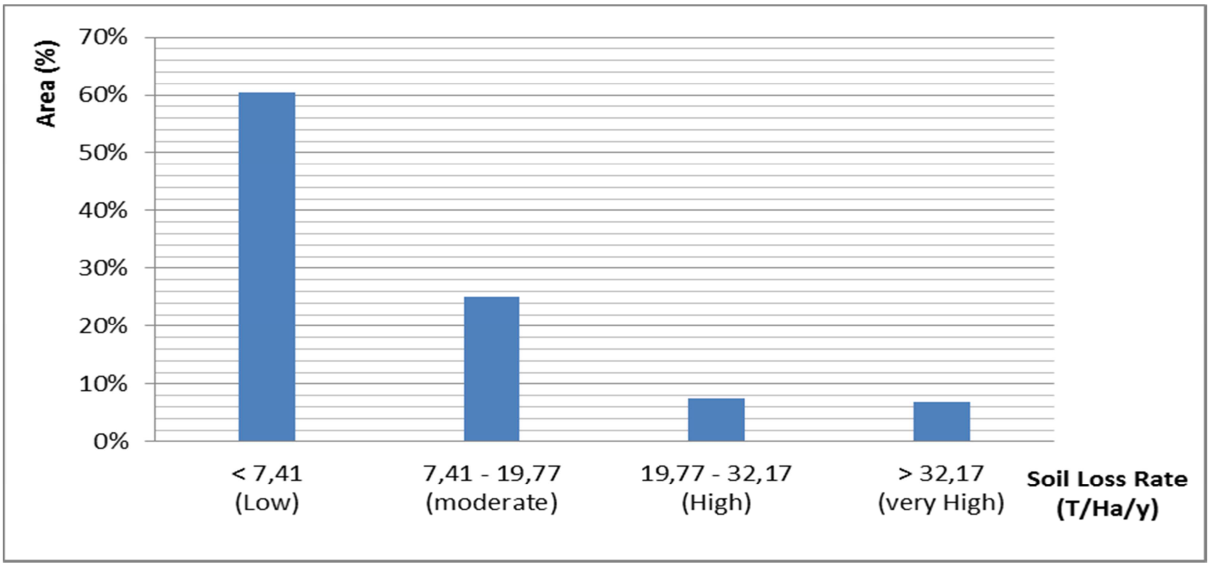


**Fig. 11.** Distribution of soil loss classes (water erosion rate).

The annual average for the entire marl area is estimated at 11 t/ha/year, a value considered moderate; Despite the dominance of values below 7.41 t/ha/year (60% of the study area), it is the high to very high erosion areas that contrast in the landscape because they are clustered on steep and elongated slopes. Critical values above 20 T/ha/year are not negligible; they occupy nearly 15% of the total surface area, and are located almost everywhere without covering vast areas in one piece.

The analysis of Erosion Potential Map shows that the intensity of erosion and the quantities of sediment produced vary mainly according to current land use, the nature of land and its slope (Fig 12).

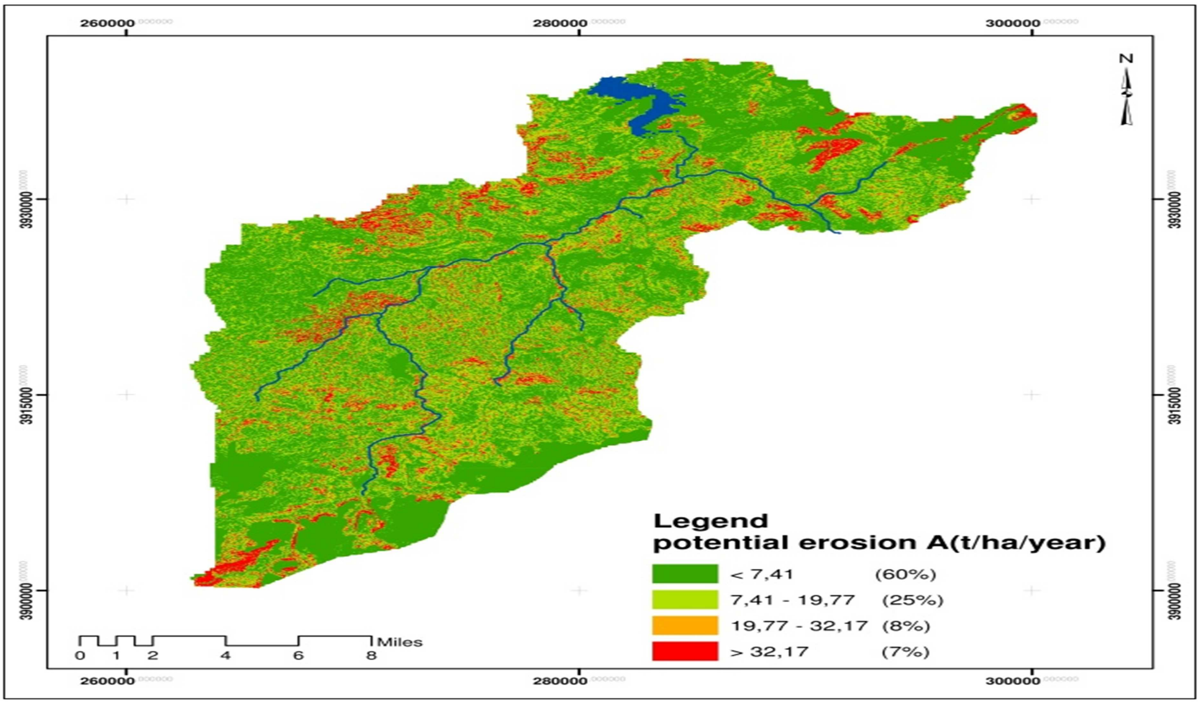


**Fig. 12.** Erosion risk in the tertiary marl area according to RUSLE.

**Conclusion**

In Oued EL-Abtal watershed, our results give a moderate average annual erosion rate (11 t/ha/year), with a dominant value below 8t/ha/year of 60%. However, these values are not reassuring, as one third of the basin has an erosion rate that exceeds 15 t/ha/year and is in risk of rising rapidly due to current environmental conditions (climate change, irregular and torrential rainfall, degradation of the vegetation cover and the absence of anti-erosive practices). Soil loss classes above 7.41 t/ha/year require a development plan to avoid any form of accelerated erosion and to restore degraded land. The priorities for management practices must be set on the basis of soil erosion risk and sediment transport downstream of Ouadi El-Abtal watershed.

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