



Soil Erosion Estimation of Wadi Medjerda in Algeria Using the Revised Universal Soil Loss Equation (RUSLE) through GIS

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Abstract

Water erosion is a major problem in the semi-arid environments of Algeria. In this vein, the objective of this study is to use the Revised Universal Soil Loss Equation (RUSLE) on the watershed of Medjerda which is located at the extreme of the North-Eastern part of the Algerian territory. Based on the crossing of various factors in raster mode under ArcGIS allows the production of diverse thematic maps corresponding to multiple factors: erosivity of precipitations, erodibility of soils, topography, the vegetal cover and the anti-erosive practices. Moreover, the risks' map of water soil erosion was obtained depending on the combination of the previous thematic maps with four class risks has been made up indicating an average erosion value of 2.68 t/ha/year. However, this value is relatively reasonable in relation to the given rate by the interpretation of the bathymetric measures carried out in the Ain Dalia dam.

Keywords: watershed, Medjerda, Dam Ain Dalia, SIG, RUSLE, erosion

1 Introduction

Algeria is subjected to a noticeable process of agricultural and altered lands erosion and substantially eroded during periods of high rainfall intensities. As a result, this process leads to the evident increase in solid transport and its corollary the increasing siltation of dams. In the light of several research, the erosion of soil is proved as a serious threat to the environment in different parts of the globe and one of the most serious problems of land degradation [1] caused by the removal, transport, and soil particles deposition [2]. Several natural and anthropogenic factors lead to the increase in soil degradation that promote the initiation and the evolution of erosion processes. The already mentioned factors are divided into two categories; those of a relatively semi-static nature (morphology, erodibility, and infiltration, etc.) and others which vary timely such as vegetal cover, land use, the intensity of rainfall and agricultural practices [3, 4, 5].

However, the impact of the associated action of these factors is manifested by an increase in the amount of materials lost, deposited downstream in stream beds, reservoir dams, lakes and sedimentation areas [6]. Since the 1950s, the problem of solid transport and the extent of the phenomenon of siltation of dams have caught the interest of many researchers. Many explanatory models of solid transport on the basis of parameters such as GIS models are since widely used to derive the necessary variables to estimate soil erosion, determine soil conservation measures and allow analysis of huge data on arid and semi-arid views. Based on an objective, spatial and comparative attitudes, the evaluation, and quantification of erosion processes is an essential step in order to propose methods of rational management of natural resources (water, soil, vegetation) for reducing the adverse effects of erosion processes.

Our study reveals that several approaches have been used to diagnose and analyze the loss of land, among these the Universal Soil Loss Equation (USLE) [7], and the RUSLE 2 which is its ameliorated version [8]. The model of RUSLE has been widely used by hydrologists all over the globe to estimate the erosion of soils according to the GIS and remote sensing environments [9-14]. Thus, the present article takes into account the use of the RUSLE approach for discovering soil loss and highlighting zones that are exposed to the risk of water erosion in the watershed of Wadi Medjerda, which could contribute to the creation of a tool to support decision-making and intervention in the development of this region.

2 The Area of Study

Concerning the sub-watershed trans boundary of Medjerda (Figure 1), it is considered as one of the five sub-basins that make up the great basin of Medjerda-Mellegue, the latter is located at the extreme of the North -Eastern part of the Algerian territory with 1438 km² area and with 276.30 km perimeter. According to Hydrographics Basins Agency (ABH), the sub-basin of interest carries the code [12 01].

The area of study is situated in the territory of the Souk-Ahras state between the meridians 7°37'E and 8°25' and the North parallels 36°05' and 36°27'. However, it is bordered in the North by the basin of the Eastern coast of Constantine, in the East by Tunisia, in the West by the basin of Seybouse and in the South by the sub basins of Mellegue upstream [12 04] and Mellegue downstream [12 05].

In effect, the Medjerda Basin is drained by the Medjerda wadi and its tributaries supplying the Ain Dalia Dam, whose water is directed to supply drinking water to Souk-Ahras town and other towns. The study area is dominated by a semi-arid climate where the average annual rainfall is between 327 mm and 723 mm, with an average of 557 mm/year.

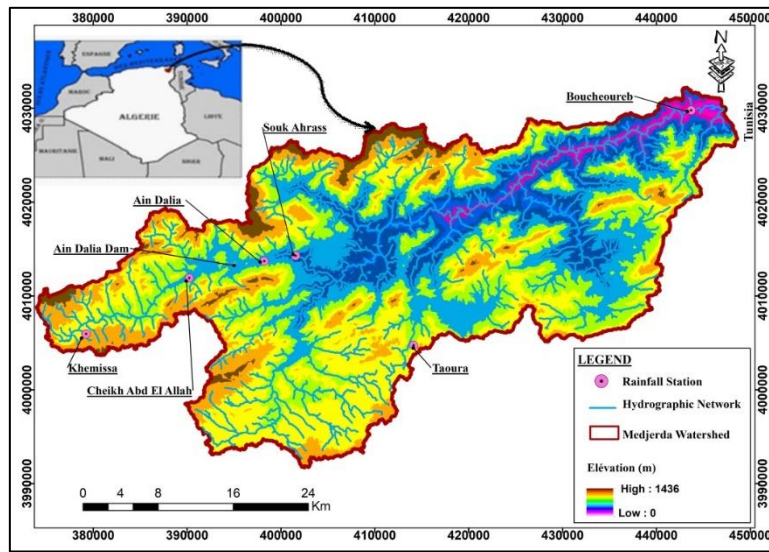


Figure 1: Geographic situation of the area of study

3 Methods

The examination of various parameters involved in erosive processes and their spatialization in thematic maps depends on the application of the RUSLE model. The use of GIS techniques for the evolution of every RUSLE factor leads to their superposition and processing. The main purpose for designing such a model is to estimate annual rates of erosion in agricultural areas for the long-term. According to [15], the equation is widely used for its simplicity and reliability in spite of the several flaws and limitations that it has. However, it also represents a standardized approach. The empirical basic equation of the RUSLE model is the Universal Soil Loss Equation which is given below:

$$A = R.K.Ls.C.P \quad (1)$$

where: A is the Average soil loss (annual); R is the erosion factor of precipitation; K is erosion factor of soil; Ls is topographic factor; C is exploitation factor of cover; P is Anti-erosive practices.

Each individual GIS file that is related to RUSLE has been built for each one and combined on a modulization process of ArcGis on cell by cell 10.4 (30 m resolution) in order to predict soil loss in a spatial approach [16]. All layers have been projected with UTM 32N using datum WGS 1984.

3.1 Model Factors

3.1.1 Erosion Factor of Rainfall (R)

The erosion factor of precipitation R is a climatic factor that reflects the effect of rainfall intensity on soil erosion. According to the equation proposed by 17, its calculation requires the determination of the total rainfall kinetic energy E_c (mm.h^{-1}) and the peak rainfall intensity in 30-minute consecutive ($\text{J.m}^{-2}.\text{mm}^{-1}$). The process of destroying the soil particles is triggered by the energy of the raindrops while the runoff ensures their transport [5]. [17] present the formula of the R erosivity like follows:

$$R = M . E_c . I30 \quad (2)$$

where: M is the coefficient that depends on the system of measurement units; E_c is the intensity of kinetic energy in 30 minutes ($I30$) of raindrops for each storm.

In the present study, it is impossible to use the prior formula because of the shortage of data on the intensity of precipitation. However, it is a general fact for most watersheds goes through in Algeria. Reliable data about the precipitations are recorded at daily, monthly, and annual scales. For such a reason we prefer to use an alternative equation based on monthly and annual precipitation (Equation 3). This formula has been used by many researchers [6, 18, 19, 20, 21]:

$$\log R = 1.74 \log \sum_{i=1}^{12} \frac{p_i^2}{p} + 1.29 \quad (3)$$

where: P_i is the monthly precipitation (mm); P is the annual precipitation (mm).

The R factor is calculated using monthly and annual rainfall data for a period of 29 to 48 years collected from 6 rainfall stations have been provided by (ANRH) the National Agency of Hydraulic Resources (see Table 3).

The values obtained for the R factor over the entire watershed were interpolated using the Ordinary Kriging method in the GIS.

3.1.2 Soil Erosion Factor (K)

For Kumar and Gupta [22], the K -factor of soil erosion is a risk parameter that affects erosion processes through soil contribution measurement. Soils differ in terms of erosion resistance, texture, structure, harshness and the content of organic matter and soil moisture. Soil resistance is weaker when the soil is less deep, and it is stronger when the soil is deeper. However, the saturation of surface soil leads to the movement of particles on the slope even at very low values as indicated by Ryan [23]. In the present study, the global soil map, which is labeled the Global Soil Harmonization Database, HWSD is employed to identify the K -factor [24].

This latter offers a wealth of information on the parameters of soil around the world by estimating the productivity of potential land helping that allows for determining land and water boundaries and improving the land degradation risks' assessment, in particular the erosion of soil (Figure 2). The HWSD is a bow matrix database of 30 seconds that has more than 16.000 different units of soils' cartography; it combines the existing regional and national updates of data about soils all over the world. The earth's territory is covered by raster database that comprise of 21600 rows, 43200 columns with 221 million grid cells that are related to harmonized data on the characteristics of the soil. The K -factor (Table 1) has been calculated by the following formulas that are proposed and used by [9, 25, 26].

$$K_{USLE} = f_{csand} \cdot f_{orgc} \cdot f_{hisand} \quad (4)$$

where: f_{csand} is a parameter that diminishes the K indicator in the soils containing of coarse sand; f_{cl-si} offers weak soil erosibility factors for soils that have strong silty clayish ratios; f_{orgc} decreases K values in soils that have organic carbon; f_{hisand} reduces the values of K in highly sandy soils.

$$f_{csand} = \left(0.2 + 0.3 \exp \left[-0.256 m_s \left(1 - \frac{m_{silt}}{100} \right) \right] \right) \quad (5)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0.3} \quad (6)$$

$$f_{orgc} = \left(1 - \frac{0.25 orgc}{orgc + \exp[3.72 - 2.95 orgc]} \right) \quad (7)$$

$$f_{hisand} = \left(1 - \frac{0.7 \left(1 - \frac{m_s}{100} \right)}{\left(1 - \frac{m_s}{100} \right) + \exp[-5.51 + 22.9 \left(1 - \frac{m_s}{100} \right)]} \right) \quad (8)$$

where: m_s is the percent (%) of sand (particles 0.05-2.00 mm in diameter), m_{silt} is the percent (%) of silt (particles 0.002-0.05 mm in diameter), m_c is the percent (%) of clay (particles < 0.002 mm in diameter) and $org C$ represents organic carbon's percent (%) in the layer.

Table 1: Estimation of K -Factor in the watershed of Medjerda

Soil sample	m_s (sand topsoil) %	m_{silt} (silt topsoil) %	m_c (clay topsoil) %	Orgc (organic carbon) %	f_{csand}	f_{cl-si}	f_{orgc}	f_{hisand}	K_{USLE}	K
Xk	40	37	23	0.56	0.357	0.865	0.983	1.00	0.3040	0.0395
Bk	38	41	21	0.63	0.369	0.883	0.978	1.00	0.3186	0.0414
Be	42	36	22	1.00	0.351	0.867	0.921	1.00	0.2799	0.0364
Cmc	31	50	19	2.01	0.402	0.908	0.763	1.00	0.2783	0.0362

Xk: Calcic Xerosols, Bk: Calcic Cambisols, Be: Eutric Cambisols, Cmc: Calcaric Cambisols

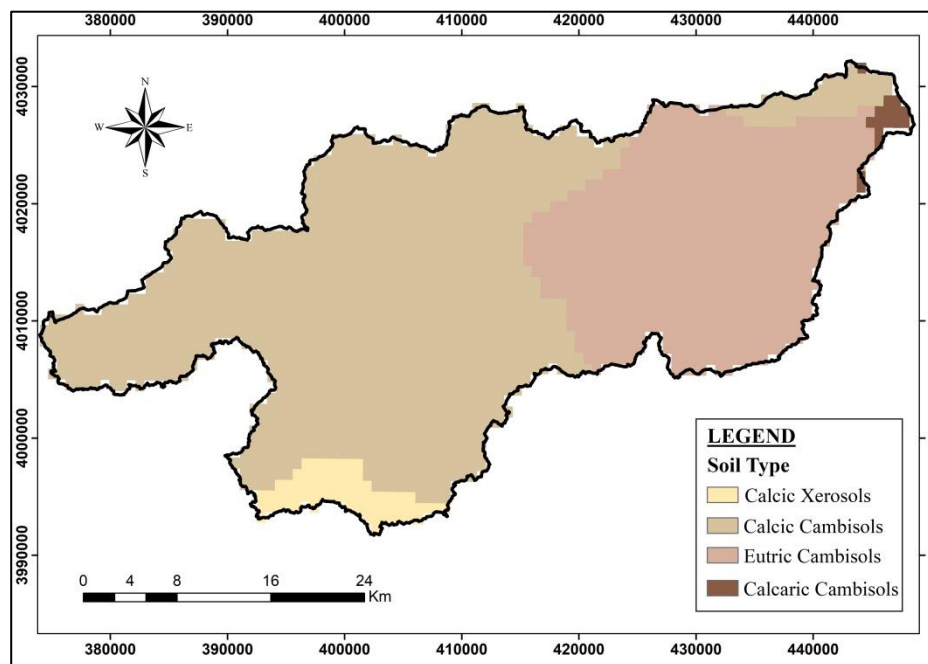


Figure 2: Study map of the types of soils within the watershed

3.1.3 Topographic Factor (*LS*)

The determination of the topographic factor *LS* in the study area is based on the use of the Digital Terrain Model and its derived maps.

On the basis of the Digital Elevation Model (DEM) of a resolution $30\text{ m} \times 30\text{ m}$ (ASTER 2011) using Esri ArcMap 10.4, it is possible to obtain the map of the slope's degree (Figure 3), the direction and the cumulative length of the slope. The latter has a big influence since it offers its erosive energy to the water. This parameter is certainly the most important concerning erosion processes because of its gravitational action and its impact on detritic materials.

There are several ways for calculating the *LS* factor namely by using approximations in GIS from the flow accumulation map. Several steps, using the raster mode spatial analysis functions under GIS have been subsequently carried out.

- The first one is related to the establishment of a raster flow direction from each cell towards to its lower altitude neighbor.
- Determining the flow direction of the theoretical hydrographic network then makes it possible for calculating the length of the slope; at first for one cell and then for all cells.

The second phase deals with calculating the slopes in degrees for each cell. Depending on slopes, the value of the exponent *m* varies [17] as shown in Table 2.

Table 2: Meters variation as a slope function [17]

slope %	$S < 1$	$1 \leq S \leq 3$	$3 \leq S \leq 5$	$S \geq 5$
m	0.2	0.3	0.4	0.5

The last step is to cross the calculations of Li and S , the final result is then divided by 100. Finally, the LS factor is determined by the following formula:

$$LS = \left(\text{Flow Accumulation} \cdot \frac{\text{resolution}}{22.13} \right)^m 0.065 + 0.045S + 0.0065S^2 \quad (9)$$

where the resolution is the cell size representing the grid (30 m) 22.13 is the standard cast field slope length; S is the slope.

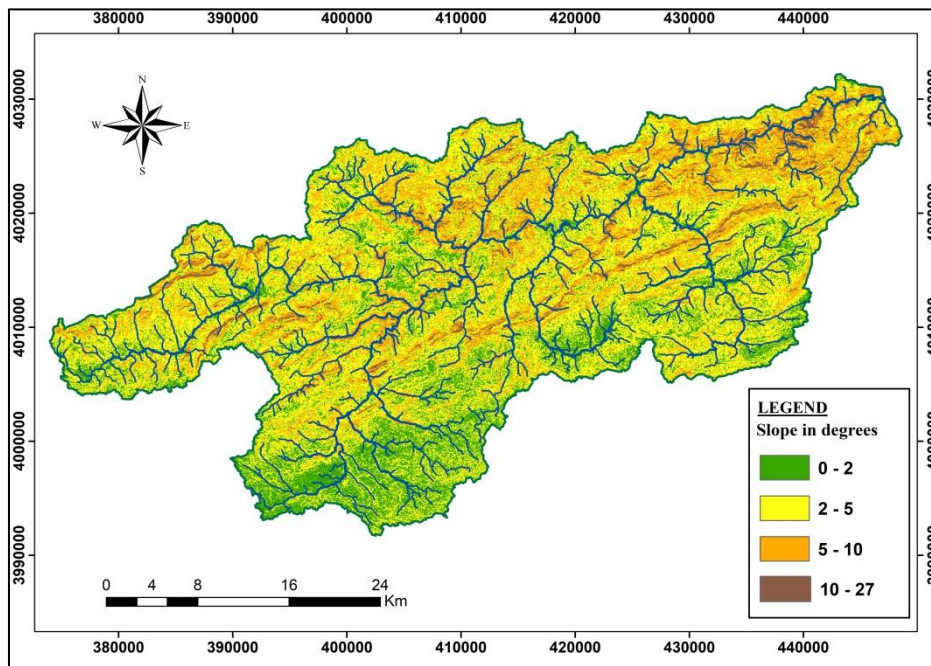


Figure 3: Slope map of the study area

3.1.4 Factor C

Kalman [21] advanced the view that vegetation plays a screen role that conditions the speed of surface runoff and reduces its erosion energy and intensity. For that reason, it is considered a pivotal factor in soil protection against erosion. In other words, this is the influence of the vegetal cover in the reduction of the erosion of soil [27].

The researchers have developed a lot of methods that estimate the factor C by using NDVI depending on the USGS website (<http://earthexplorer.usgs.gov>) for the evaluation of soil loss [28, 29]. In the above-shown study, the Normalized Difference Vegetation Index (NDVI) estimates the values of this parameter. The difference between the reflectance of the Red Band (R) and of the Near Infrared Band (NIB) of the electromagnetic spectrum is expressed by the

mathematical formula (Equation 10). This indicator is linked to the vegetal nature and its own percentage. The land-use map was developed from a LandsatTM8 image taken on 27/3/2021 with a 30 m resolution, which was previously processed, using the index of vegetation normalized NDVI based on the colored compositions of the image bands (bands 4 and 5).

$$NDVI = \frac{NIB-R}{NIB+R} \quad (10)$$

where *NIB*: Near infrared band

A: Red band

The highest percentage of vegetal cover is reflected by the maximum value of NDVI. This means that zones that are void of vegetation (bare soil and water bodies) have a weak value of NDVI (Figure 4). [30] has used the following equation for calculating the *C* parameter:

$$C = 0.9167 - 1.1667 (NDVI) \quad (11)$$

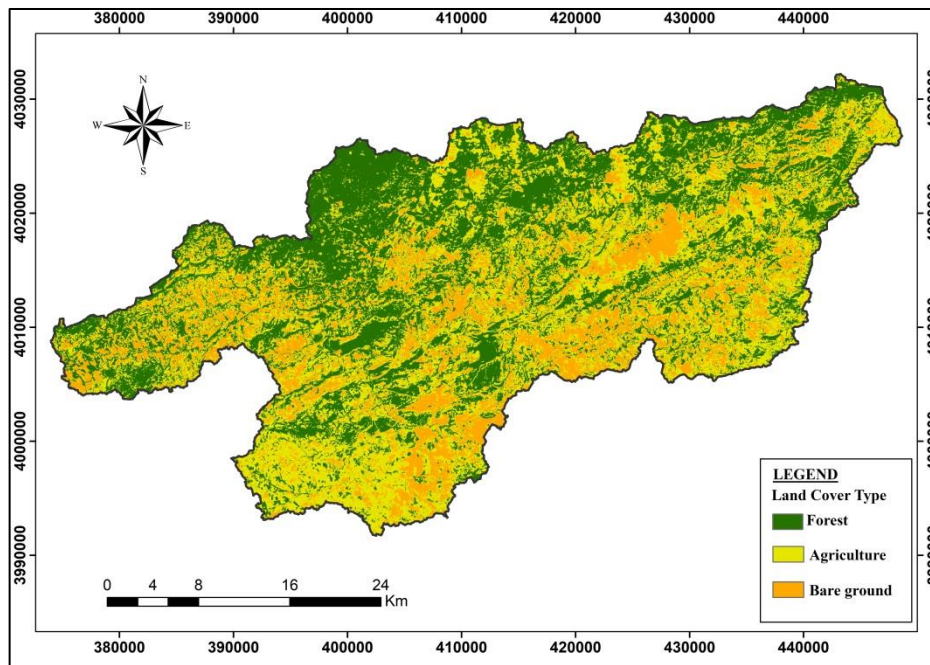


Figure 4: Map of vegetal cover type. (NDVI) data source

3.1.5 Factor of Anti-Erosive Practices (*P*)

The practices that are more efficient for soil conservation are cropping in curves, alternating bands or terraces, reafforestation berms, earthing and ridging that reduce the erosive effect of precipitation and runoff and hence reduce the quantity of the erosion of soil [31]. It varies from 1 for land on which none of the above practices are used to approximately 0.1 when in the case of low slope, partitioned timbering is practiced [32].

In the study area, anti-erosion schemes do not exist; cultivators never use anti-erosion cropping practices. Indeed, the crops are particularly cereal ones, and the plowings are rarely parallel to

the level of curves. In the absence of information on soil conservation practices, the P factor was assigned a value of 1.0 to the entire area of the watershed.

4 Results and Discussion

4.1 Factor R

By using the rainfall data of six rainfall stations, the factor R values for every station have been estimated. Subsequently, the values of factor R of the entire watershed have been interpolated using ordinary kriging interpolation in the GIS.

The spatial spreading of erosivity of rainfall in the Wadi Medjerda watershed shows that the values of factor R vary from 56 to 100 (MJ mm/ha/h/ year). These values of R that are above 56 (MJ mm/ha/h/ year) show that the entire watershed is exposed to a severe degree of climatic aggressiveness.

Based on precipitation characteristics, the values of factor R that are very low have been recorded in the North-East portion of the watershed and the ones that are very high have been recorded in the North-West and South-West portions. In accordance with Table 3 in excess of 70% of the area of study is exposed to heavy rainfall erosivity then it introduces the values of factor R that are superior to 56 (MJ mm/ha/h/ year) it is therefore concluded the basin's erosive power of precipitations is pivotal. The erosion intensity related to the amount and intensity of precipitations is increasing from the East of the watershed to the West with a slight decrease in the Western part of the region (Figure 5). The Wadi Medjerda watershed is prone to a high degree of climatic impact.

Table 3: Average annual precipitations and R - factor rates

Stations	code	Data X	Y	Annual precipitation (mm)	Period (number of years)	Erosivity
Souk Ahrass	120101	967.25	342.25	564.9	1970-2018 (48 y)	80
Khemissa	120104	945.5	332.5	496.36	1970-2018 (48 y)	73
Taoura	120105	980.55	331.55	593.70	1972-2018 (46 y)	81
Cheikh AbdEllah	120113	956.55	339.25	640.5	1975-2018 (43 y)	90
Ain Dalia	120115	956.1	339.15	723.9	1989-2018 (29 y)	100
Boucheoureb	120116	1008.288	360.422	327.4	1999-2018 (19 y)	56

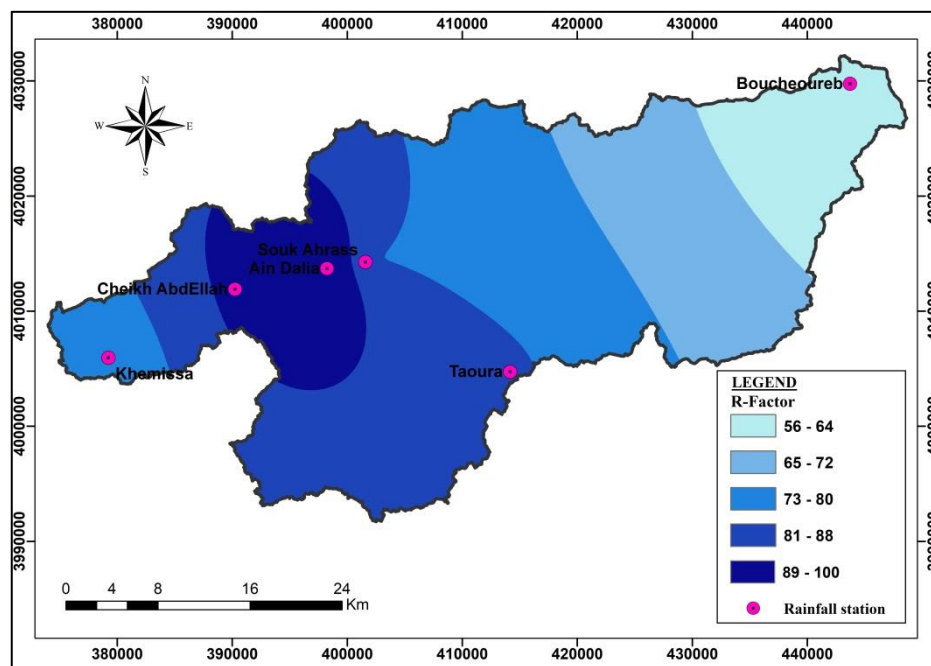


Figure 5: Map of the Rainfall Erosivity Factor R

4.2 Erodibility factor of Soil (K)

The watershed of Medjerda wadi includes four different soil types with different characteristics. The composite map of factor K has been generated to designate the spatial spreading of erodibility (Figure 6). The soil map has been reclassified with the assigned values of factor K . the values of factor K range from 0.0362 to 0.0414 t.ha.h/ha.MJ.mm. The highest values of factor K are related to soils highly vulnerable to erosion which are the Calcic Cambisols in this study; it is located in the greatest part of the North-West of the watershed.

The Soils of the area of study are considered as moderately sensitive to erosion with a moderate value of 0.0388 t.ha.h/ha.MJ.mm on the basis of [33] Resistance Classification related to Soils' Erosion which is based on the factor K (Table 4).

Table 4: Classification of Soil Resistance on Erosion by [33]

The Type of Soil	Factor K (t.ha.h/ ha.MJ.mm)
Very resisting soils to erosion	$K < 0.0132$
Soils fairly resistant to erosion	0.0132 – 0.0329
Soils moderately sensitive to erosion	0.0329– 0.0461
Soils fairly sensitive to erosion	0.0461 – 0.0593
Soils very sensitive to erosion	> 0.0593

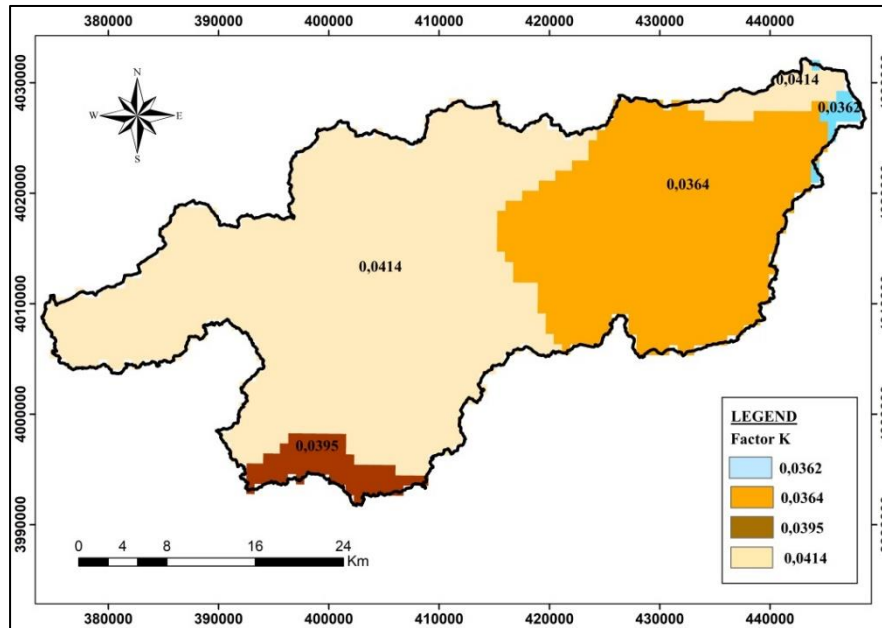


Figure 6: Spatial Distribution of soil Erosibility Factor K in (t.ha.h/ha.MJ.mm)

4.3 The Factor of Topography (*LS*)

Based on calculations, it is shown that the values *LS* range from 0 to 23.755 having 5.36 as an average (Figure 7). The obtained map has designated that the factor *LS* is directly related to the topography. The highest values take place primarily in mountainous areas of the high valley of the Wadi Medjerda watershed whereabouts the high and very high slopes prevail. This parameter presents a risk factor of erosion as a function of slope areas on the scale of the watershed. As the factor heightens, the watershed becomes more affected by erosion.

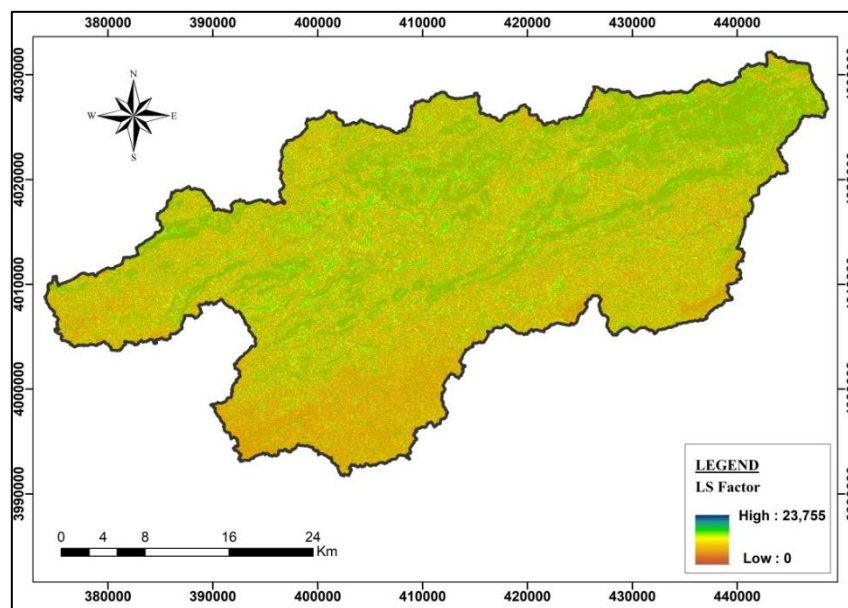


Figure 7: LS factor map of the study area

4.4 C-Factor

The surface cover of soil determines factor C through the vegetation and the height of plant strata a . In the database assigned to it, the values of factor C for each land use have been determined from the tables of [17, 34], it is between 0 and 1 for each type of vegetal cover in the area of study. Table 5 and Figure 8 show the vegetal cover distribution and the factor C values in the Wadi Medjerda watershed.

Areas with high vegetation are associated with the lowest values ($C < 0.24$) provide better soil protection and correspond to forest formations where human influence is low. The highest values ($C > 0.25$) correspond to soils with a higher susceptibility to erosion. These results have confirmed that bare grounds are more affected by erosion and soil loss while vegetative cover zones are highly resistant to this phenomenon.

Table 5: Distribution of the Factor C in the Wadi Medjerda Watershed

Type	C-Factor
Water Plan	0
drill	0.24
Agriculture	0.45
Bare land	1

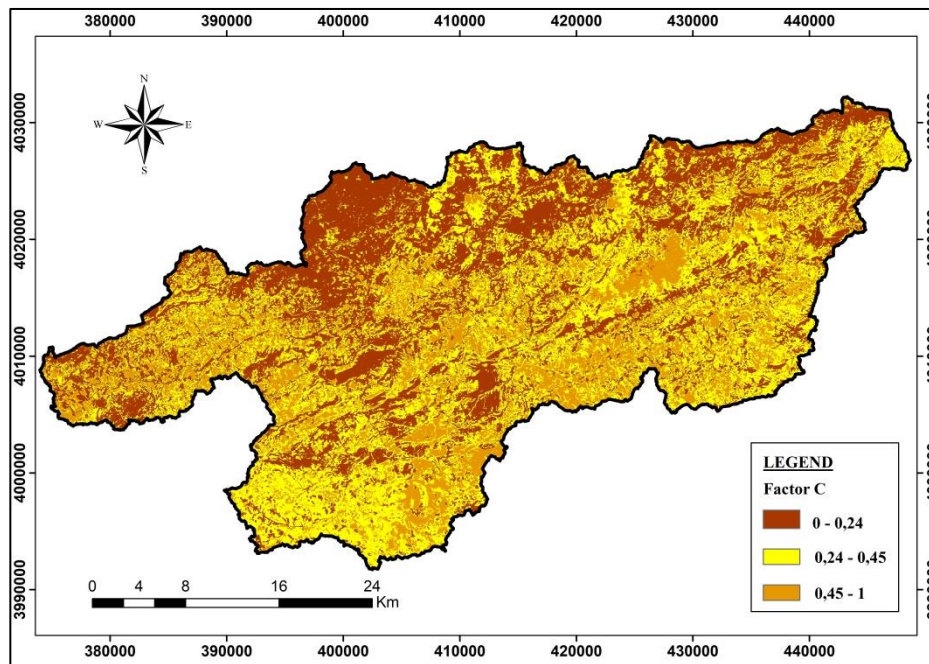


Figure 8: Spatial distribution of factor *C*

The Limitations of the study include the delay in adopting the bathymetry measures data the National Agency of Dams and Transfers (ANBT), as well as the monthly and annual rainfall data at the level of (ANRH) the National Agency of Hydraulic Resources, where the administrations were closed because of the Covid 19 (mid-March – mid-September 2020).

5 Estimated Potential Annual Soil Losses (*A*)

The goal of this article is to evaluate soil losses provoked by the erosive phenomenon and to delineate areas possibly delicate to the erosion of water in the Wadi Medjerda watershed by applying the RUSLE empirical model of soil erosion integrated in GIS to identify critical areas. The evaluation of soil losses due to water erosion obtained by the crossing of factors in raster mode under ArcGIS and the multiplication of layers introduced by the parameters and thematic maps of RUSLE, in particular, the climatic aggressiveness *R* (or erosion of precipitation), the erodibility of soils *K* and the mixed effect of the degree and the length of the *LS* slope, the vegetal *C* cover and the practices of anti-erosion *P*. The cartographic representation of these factors (thematic maps) and their crossing led to the evolution of a summary map highlighting four classes of soil vulnerability to water erosion, resulting from an average erosion rate of 2.68 (t/ha/year). This rate is relatively reasonable with the rate given by interpreting the bathymetric measurements made in the Ain Dalia dam.

The classification in Figure 9 shows that the weakest erosion category is associated with gently sloping of 2 degrees areas which dominates the entire southern part of the area of study. It is chiefly composed of agricultural land. The low erosion category concerns surface whose soil loss is less than 4 (t/ha/year) representing 40.54% of the surface of the watershed. 31.95%

of the area of study is exposed to moderate erosion; it is a mountainous region with slopes greater than 8 degrees where forests are predominant and only subsistence agriculture is practiced by the rural population (Table 6). Severe erosion takes place in some parts of the watershed exclusively in soils of high erodibility and steep landforms are primarily located in the Northern part of the watershed.

Table 6: Distribution of Soil loss A Classes in Wadi Medjerda Watershed

Soil loss (t/ha/year)	Area (ha)	Area (%)
< 2	35920.97	24.98
2-4	58296.02	40.54
4-7	45945.96	31.95
7-16.7	3637.05	2.53

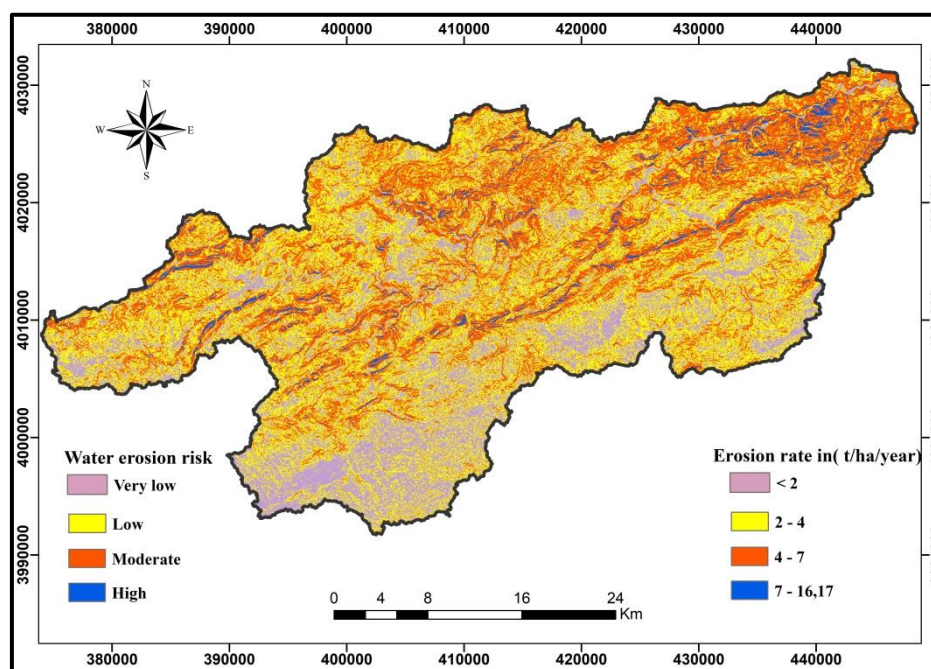


Figure 9: Map of erosion risk in the watershed Wadi of Medjerda

6 Validations

In this article, the obtained results through the RUSLE model application must be validated against actual sediment transport measurements. To this end, the Ain Dalia dam has been the subject of bathymetry measures by the National Agency of Dams and Transfers in different periods of time 2004 and 2019.

The results show that the siltation of the reservoir since the launching of the 1988 dam was 7.39 million cubic meters which corresponds to a loss of 9.012% of its initial capacity or an average annual volume of 238 387.10 m³/year; this reduction in water storage capacity is due to soil

erosion. The following Table 7 summarizes the evolution of the loss of dam retention capacity. It is considered that the average rate of erosion reaches 2.48 t/ha/year when the density of settled sludge is 1.5. This value is relatively close to the value obtained by RUSLE, the difference between the two values is estimated at 7.46%; this shows that the rates of soil erosion estimated by the model of RUSLE and by the bathymetric measurements are compatible to each other. The map is an indispensable tool in the fight against erosion. It contributes to an overview of threatened areas and identifies areas requiring priority intervention with a view to sustainable land management.

Table 7: Evolution of the Loss of Capacity of the Ain Dalia Dam

	Launch Year 1988	2004 Survey	2019 Survey
Capacity (hm ³)	82.00	76.08	74.61
Loss compared to 1988 (hm ³)	-	5.92	7.39
Loss in %	-	7.22	9.012

7 Conclusion

On the light of this study, the methodology of water erosion characterization is applied through the use of a spatialization and quantification of the principal factors involved in the erosive process, the estimation and spatial distribution of the erosion of soil in the Medjerda wadi basin employing the Universal Soil Loss Equation (RUSLE) and GIS techniques estimating that the basin has had to cope with very low to high soil loss. It is worthy to note that the outcomes indicate that the rainfall erosivity R-factor of RUSLE was found to be 78 MJ mm/ha/hr/yr and the soil erodibility K-factor varied from 0.0362 to 0.0414 t.ha.h/ ha.MJ.mm. Slopes in the catchment varied between 0 degrees and 27degrees having LS factor values ranging from 0 to 23.755. The C factor was computed from NDVI (Normalized Difference Vegetative Index) values derived from Landsat-TM8 data. The P factor was assigned a value of 1.0 to the entire area of the watershed. The annual soil loss estimated in the watershed using RUSLE is 2,68 t/ha/yr. The map of soil loss has been classified into four risk classes on the basis of the quantity of soil loss: very weak (< 2 t /ha/y), weak (2–4 t /ha/y), moderate (4–7 t /ha/y), strong (7–16.17 t /ha/y). Hence, the average annual soil loss map will be helpful in identification of priority areas for implementation of soil conservation measures and effective checking of soil loss.

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