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Research article

Contribution of GIS for water erosion risk assessment in the Sahbi River watershed (North-West of Tunisia)

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Abstract
Tunisia, a southern Mediterranean country, is characterized by the vulnerability of its resources, mainly water and soil, which are subject to various forms of degradation, the most common of which is water and wind erosion. Indeed, water erosion is intensifying in several regions of the world and especially in North Africa, affecting nearly 3 million hectares of agricultural land in Tunisia. It causes disastrous damage upstream and downstream of hydraulic infrastructures while affecting the sustainability of the latter. Water erosion is caused by a combination of several physico-climatic factors, namely rainfall, relief, cultivation practices, land use and soil characteristics. In the present study, we will adopt the RUSLE (Revised Universal Soil Loss Equation) model to evaluate the quantities of soil losses at the scale of the Sahbi River watershed (north-west Tunisia). The application of the RUSLE approach combines the main erosion factors in a geographic information system.
The resulting soil loss map shows a low erosion (< 4 t/ha/year) covering 87.94% of the total surface area of the basin, and a very high erosion (> 33t/ha/year) not exceeding 1% of the surface area. The areas with high erosion rates are mainly recorded at the level of areas characterized by a steep slope, high erodability and low vegetation cover, which shows the importance of this phenomenon at the level of the studied basin.

Key words: Soil erosion, RUSLE model, GIS, watershed, Tunisia.

1. Introduction

All life on earth depends on a thin layer of soil commonly known as the 'pedosphere'. It is very vulnerable to degradation and erosion. According to Soutter et al. (2007), the term erosion encompasses all forms of wear and tear affecting the surface layer of the earth's crust. These are usually distinguished according to the nature of the agent involved: water erosion, wind, glacial, river and marine. Water erosion appears as an alarm signal of the imbalance between the soil environment and its operating system. However, several authors have mentioned that this phenomenon manifests itself in a trilogy, (i) the detachment of particles from their environment, (ii) their transport followed by (iii) the deposition of particles in a sedimentation basin under the effect of rain and runoff energy (Le Bissonnais et al. 2002; Antoni et al. 2006; Zhang et al. 2003a; 2019b). This phenomenon continues to take on great proportions linked to several natural and anthropic factors favouring the development of erosion processes, such as the aggressiveness of the rains, the vulnerability of the land and the unfavourable impact of human activities, such as deforestation, fires and overgrazing.

The consequences of this process are numerous and diverse. The stripping of soil profiles and the transfer of sediment, carbon and nutrients to crops are just examples. In addition, they involve the acceleration of the fertility degradation of cultivated soils. In addition, the materials removed from the soil, namely nutrients and pesticides, are deposited in the hydrological networks, thus leading to the deterioration of water quality and the rapid siltation of hydraulic works, especially hill lakes. Soil erosion can also lead to landslides or mudslides, thus causing material and human damage that is often disastrous and spectacular.

For centuries, geographers considered North Africa to be very sensitive to water erosion in all its forms. Indeed, it affects about 45 % of the land in Tunisia, 40

% in Morocco and 45 % in Algeria in the Tellian areas (kheir et al. 2001). Erosion is not limited to the Maghreb region; it is rather almost everywhere in the world. According to the United Nations (UN, 2002), water erosion affects 14.3% of the surface of South America and 26% of Central America. In Europe, according to the European Environment Agency (AEE, 2005), the phenomenon affects approximately 17% of its surface. In Asia, China lost an area of arable land during the period 1957-1990 equal to that of all the cultivated land in Germany, Denmark, France and the Netherlands combined, mainly as a result of land degradation (FEM et FIDA 2002).

The extent of water erosion and the seriousness of its consequences in recent years have largely contributed to the development of preventive methods and forecasting models, both qualitatively and quantitatively. Currently, digital mapping techniques, satellite image processing and geographic information systems (GIS) based on several models - some of which are empirical, such as the USLE model and its revised versions (RUSLE), are the most widely applied to study water erosion. They make it possible to specialize all the natural factors that contribute to the process of water erosion, in order to locate highly sensitive areas that require rapid intervention by developers to simulate scenarios for the evolution of basins against erosion.

This work is based on the RUSLE model (the revised universal soil loss equation) (Renard et al. 1997) coupled with a Geographic Information System (GIS). This approach makes it possible to estimate soil losses and establish a spatial distribution of erosion risks on the scale of the Sahbi River watershed. The basic data of this model are those of the digital terrain model, the mean annual rainfall, the hydrographic network and the values of the erosion factors, namely the rainfall erosivity (R), the soil erodibility (K), the topography (LS), the vegetation cover (C) and the cultivation practices (P). Several studies show that the RUSLE model has provided better estimates of erosion at the watershed scale in Mediterranean countries (Dermirci and Karaburun 2012; Toumi et al. 2013; Tahiri el al. 2016; Fernandez and Vega 2016; Karamesouti et al. 2016; Abdo and Saloum 2017; Omar et al. 2019). The objective of this study is to make a precise estimate of soil loss in the Sahbi River watershed, as well as to develop a useful support for the realization of anti-erosion development plans.

2. Material and methods

The Sahbi River watershed (Fig.1) located in North-West Tunisia in the area of Drablia and Foundouk debbiche of the Rouhia delegation of the Siliana governorate with a surface area of 8.70 Km^2 and a perimeter of 12.58 Km. The future hill lake on Sahbi River is among the 6 hill lakes programmed in 2015 by the Regional Commission for Agricultural Development (CRDA) of the governorate of Siliana. The main objective of these hill lakes is mainly intended for irrigation and flood protection of the agricultural plains. The study area is characterized by an altitudinal variation, ranging from 714 m in the plain areas to 1020 m on the highest peak on the flank of Jebel Bou Rokba (Fig.1). Its climate is semi-arid under a cool winter. It is marked by irregular rainfall, low winter temperatures and high summer temperatures. In the absence of a rainfall station in the Sahbi River catchment area, we used the nearest station to Rouhia which is less than 6 km from our catchment area. The average annual rainfall for the period 1987-2012 is 301.4 mm (Table 4). Average monthly temperatures vary between 8.8°C and 26°C with an interannual average of 16.04°C, recorded at the Sbiba city station which is the closest to our study area. As far as hydrology is concerned, the hydrographic network that drains the watershed of the Sahbi River is quite dense on the right bank, with highly developed gullies mainly in the upstream part of the basin where the tributaries take on a great importance and branch out only on the left bank. On this basin, the concentration of runoff water is in the downstream part. The main tributaries of Sahbi River, as well as its downstream course, take the northeast-southwest direction, especially in the upstream and middle part of the watershed (Fig.1).

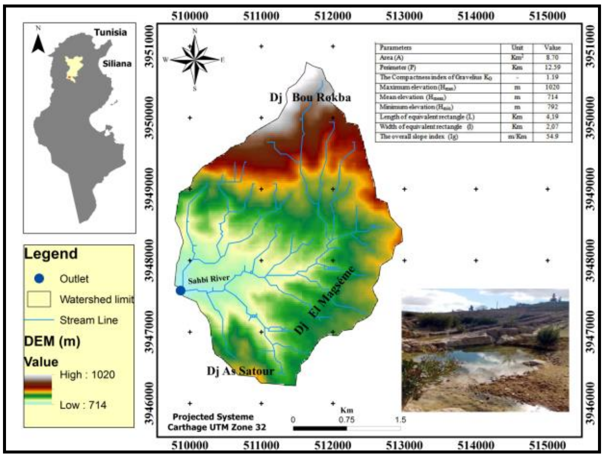

Fig. 1. Geographical situation and DEM of the Sahbi River watershed

In this basin, we were able to identify 2 lithological units presented on the geological map of the Sahbi River watershed. It is essentially occupied by Eocene terrains; one distinguishes grey greenish lumachellate clays of the Upper Lutetian-Preabonian with a percentage of surface occupation that exceeds 58%, which is surmounted by alternating lumachellate clays and sandstone limestone of the Lower and Middle Lutetian with 42%. The Lower Lutetian-Preabonian series are affected by intense fracturing in several directions, namely NE-SW, NW-SE, E-W and N-S. This fracturing facilitates the erosion and detachment of the pebbles and large boulders that line and occupy the bed of the River. The soil structure of the Sahbi River watershed presents three classes of soils: raw mineral soils (58.3%), poorly developed soils (2.3%) and complex soils (39.4%).

Land use in the Sahbi River watershed is characterized by the diversity of vegetation cover. Forest formation covers of 462 ha, or 53.1% of the study area. More than half of this formation is occupied by scrub and scrubland with trees and scrub and scrubland without trees, the remainder (199.9 ha) is formed by forests of Aleppo pine (Pinus Halepensis) and various conifers which are found on the peaks of Jebel El Magséme, at altitudes above 750 m. Unproductive land is formed by very degraded rangelands, rocky terrain that is very common in the downstream part at the outlet, and urbanized land that cover an area of 331.6, or 38.1% of the basin. These areas are found mainly in the central part and throughout the basin. The rest of the area is occupied by agricultural land (cereals and olives), they occupy 76.7 ha, or 8.8% of the area.

The slope plays a very important role with respect to the erosive phenomenon. It influences the speed of the flows in order to tear off and transport the particles. The greater the slope is, the greater the effect of soil degradation becomes. The Sahbi River watershed predominates medium to very steep slopes which are identified especially in the upstream part of the basin which is characterized by rugged relief; they are represented by Jebel Bou Rokba, Jebel El Magséme and Jebel As Satour. This allows us to attribute a high rate of erosion. However, the weak slopes are concentrated at the level of the plain. The dominant slopes of the Sahbi River watershed range between 5 and 10% (Fig. 2).

Referring to the slope map (Fig. 2), we notice that the low to medium slopes occupy about 68.5% of the study area. This area favors superficial soil stripping. However, 31.5% of the surface considered is characterized by fairly steep to very steep slopes.

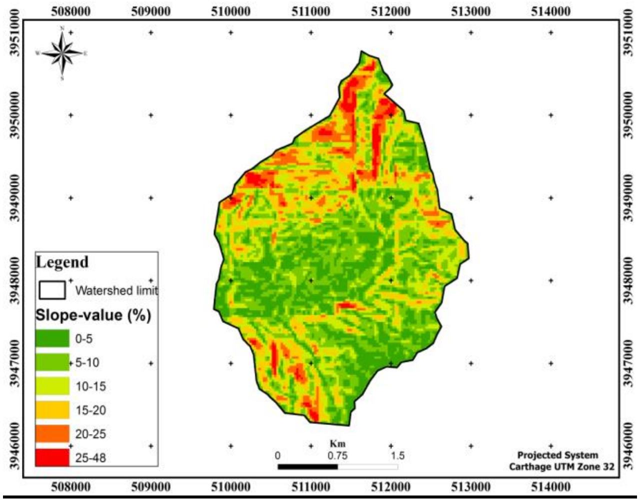

Fig. 2. Slope class map of the Sahbi River watershed

3. Materials and methods

3.1 Presentation of RUSLE

The RUSLE model (Revised Universal Soil Loss Equation) (Renard et al. 1997) is a revised version of the Universal Soil Loss Equation (USLE) originally developed by Wischmeier and Smith 1978. It is written in the following form:

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

With: A: the annual rate of soil loss expressed in (t/ha/year); R: rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$); K: soil erodibility factor (t ha h/ha MJ mm); LS: topographical factor, obtained by combining the slope and its length; C: vegetation cover factor and P: factor of anti-erosion cultivation techniques.

The flowchart below summarizes the operation of the RUSLE model, in order to quantify the rate of soil loss and to map the areas sensitive to water erosion over the entire Sahbi River watershed (Fig. 3).

3.2 Data used

Evaluating each of these factors requires a series of data processing steps. Indeed, the climatic data used in our study come from the Rouhia delegation station, the closest to the studied basin. They mainly allowed to determine the climatic aggressiveness (R). These data are extracted from the archives of CRDA Siliana, and from existing documents relevant to the climatic study of our study area. The value of R adopted in the RUSLE equation is the average of those summed over a multi-year period (1987-2012) (Table 4).

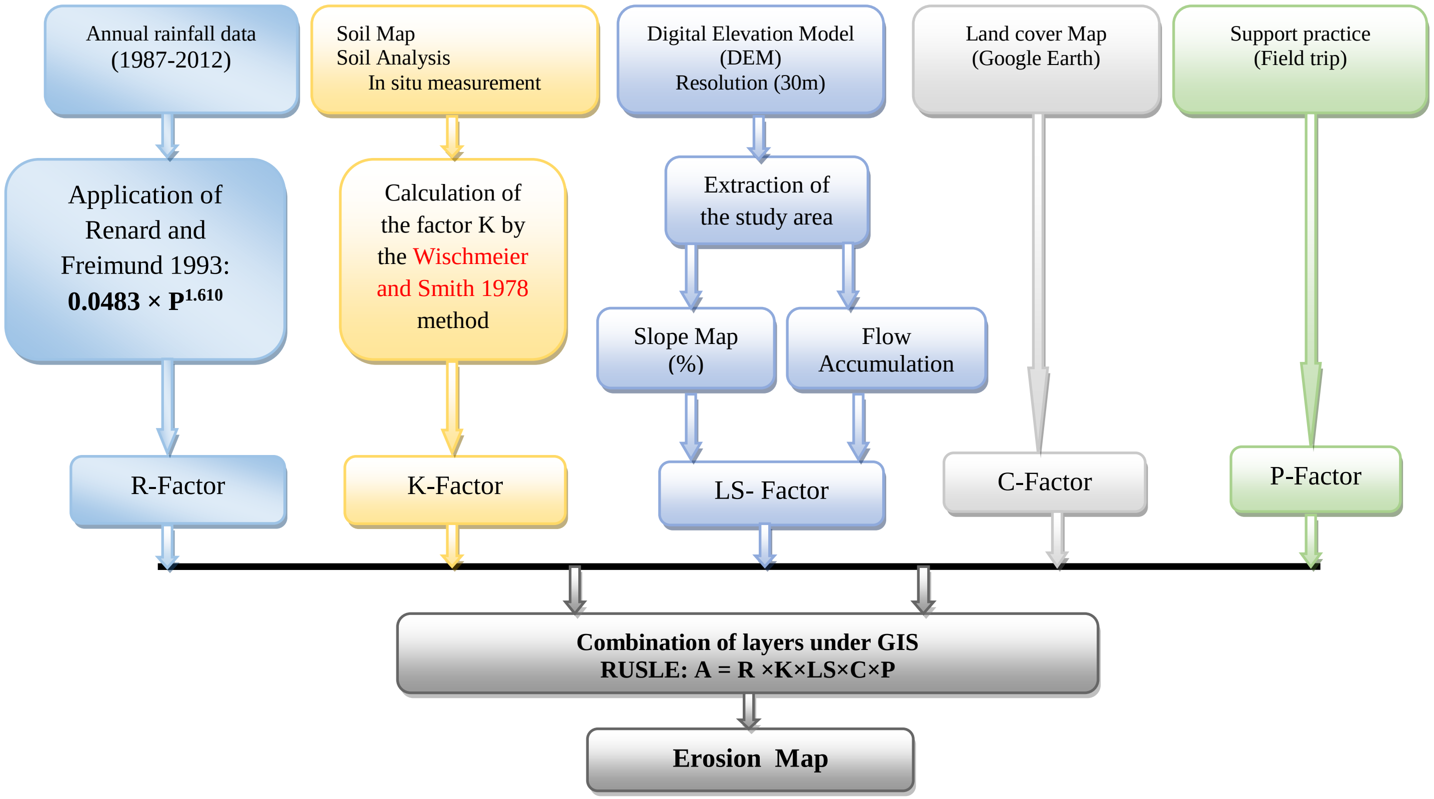

Fig. 3 Organization chart describing the methodology adopted

The LS topographic factor is calculated after a certain amount of pre-processing of the SRTM (Shuttle Radar Topography Mission) type DEM with a resolution of 30 m (http://opentopo.sdsc.edu/datasets) under a tool integrated in the Arc-Gis software. Indeed, the first step consists in filling the cuvettes to eliminate the imperfections in the DEM thanks to the "Fill" function. The second step allows the creation of the flow direction map. From the latter, the flow accumulation map is determined. The third step consists in creating the slope map (S factor expressed in %) of the Sahbi River watershed from a digital model using the "Slope" command. Finally, the integration of the flow accumulation map and the slope map under the "Raster-Calculator" tool of the "Spatial Analyst tools" module while applying the mathematical equation of the Wischmeier& Smith (1978) model, allows to evaluate the distribution of LS values in the whole surface area of the studied basin.

The soil data for the Sahbi River watershed were extracted from the soil map of the area and from the agricultural map, provided by the CRDA of Siliana. These data are complemented by soil profiles dug at the time of the field prospection. First of all, the different classes of soils that make up the study area were identified on the pedological map. Secondly, soil profiles were dug at the level of each class. These samples were analyzed to determine the organic matter content and particle size composition of each sample. Finally, the values obtained from these parameters allowed us to define an average erodibility for each soil class; therefore its values will be used in our study to obtain a thematic map of soil erodibility for the Sahbi River watershed. Thus, the land use map was mainly extracted from the agricultural map of Siliana based on recent data digitised from Google Earth. It was used to determine the vegetation cover factor (C) for this watershed. Factor indexation (P) is based on the results of studies carried out in Tunisia by the FAO (1977).

3.3 R factor

The erosivity factor refers to the capacity of a rainfall to cause erosion (Zouagui et al. 2018). Raindrops can fragment aggregates and especially detach particles from their surface (Bisonnais et al., 1995). Because of the absence of rainfall data in the Sahbi River watershed, we have used the formula most adapted for the Tunisian regions is the one developed by Renard and Freimund (1993), which takes into consideration the annual rainfall at the Rouhia delegation station which is the closest to this site (6 Km).

$$R = 0.0483 \times P^{1.610} \text{ (Renard and Freimund 1993)} \quad (2)$$

Where P is the average annual rainfall (mm)

3.4 K factor

The erodibility of the soil is defined as its intrinsic ability to be detached and transported by rainfall and runoff (Le Bisonnais et al. 1995; Zouagui et al. 2018). The K-factor is determined according to several soil characteristics such as texture, the presence of organic matter, permeability and depth (Khemiri et al. 2021). It has been calculated using the formula of Wischmeier and Smith (1978).

$$100K=2.1 \times M^{1.14}\times10^{-4} (12–a) + 3.25\times (b–2) + 2.5\times (c–3) \quad (3)$$

Where: K is the erodability factor

M is calculated by the formula M = (% fine sand + silt) × (100 - % clay)

a is the percentage of organic matter,

c is the code of the structure

b is the code of permeability

The various rock types and their structures give an indication of the infiltration capacity of the areas occupied by rocks and soils and consequently of the amount of soil susceptible to erosion (Boukheir et al. 2001). Low rock infiltration indicates that a large amount of water runs off, therefore a large amount of soil can be washed away (Toumi et al. 2013). Soil structures and permeability and their respective codes were evaluated using the structure-permeability evaluation triangle (Jones et al. 1996). Whereas, the percentages of sand, silt, clay and organic matter were determined by soil analyses. The values obtained from its analyses made it possible to define an average erodibility for each soil class, in order to establish an erodibility map for our studied basin.

3.5 LS factor

The LS factor is the combination of two sub-factors: the inclination (S) and the slope length (L). According to (Roose 1994), several parameters have a considerable influence on soil erosion, such as length, shape and especially slope inclination. The speed of runoff increases with the increase of this factor. In fact, the length of the slope conditions the flow speed and the transport of particles. The steeper the slope, the greater the runoff flow rate and the more sufficient it becomes to remove sediment and dig gullies.

In our case we will work with the equation developed by Wischmeier and Smith (1978) which has been used by several authors and has given better estimation results (Vezena and Bonn 2006; Khosrowpanah et al. 2007; Park 2007; Rodríguez & Suárez 2010 and Toumi 2013).

$$LS= \left(\text{Flow accumulation} \times \frac{\text{Résolution}}{22.13}\right)^{m} \times (0.065 + 0.045\times S + 0.0065\times S^2) \quad (4)$$

Where: S is the slope (%)

m is a parameter relative to each class of slope (Wischmeier and Smith 1978) (Table 2).

Table 1. Classification of slopes according to areas

N° of class	Slope (%)	Slope class	Area (ha)	Area (%)
1	0-5	Very lowslope	90	10.35
2	5-10	Low slope	269.9	31.02
3	10-15	Meduimslope	235.6	27.08
4	15-20	Fairlysteepslope	145.5	16.72
5	20-25	Steepslope	71.3	8.20
6	>25	Very steepslope	57.7	6.63

Table 2. Value of 'm' relative to each class of slope (Wischmeier and Smith 1978)

Slope (%)	m
>5	0.5
3-5	0.4
1-3	0.3
<1	0.2

3.6 C factor

Plant cover protects the soil from erosion by slowing the speed of runoff and increasing soil infiltration. The spatial distribution map of the vegetation cover factor (C) of our study area is obtained from the agricultural map of the Siliana region and from Google Earth satellite images. Thus, the C values assigned to each land use class, determined by referring to the work of Cormary and Masson (1971) in Tunisia and to the applications of the RUSLE model, particularly on the hill lake Abdessaddok (Zante et al. 2003) and on the hill lake El Hnach (Zante et al. 2001) in the Maktar region (Tunisia).

3.7 P factor

Factor (P) reflects the soil conservation actions that are carried out to curb the extent of water erosion. According to Wischmeier and Smith (1978), the values of (P) are less than or equal to (1), the value of which (1) is assigned to land on which there are no anti-erosion practices. These values are determined on the basis of studies carried out by the FAO in Tunisia in 1977 (FAO 1977) (Table 3).

Table 3. P-factor for contour crops, benches and alternate strips (FAO 1977)

Slope %	Contour lines	Alternating strips	in benches a	in benches b
1 – 7	0.5	0.25	0.5	0.10
8 – 12	0.6	0.30	0.6	0.12
13 - 18	0.8	0.40	0.8	0.16
19 - 24	0.9	0.45	0.9	0.18

4. Results and discussion

4.1 The rainfall erosivity factor (R)

The results of the calculation show that the average annual erosivity index is of the order of 473.55 MJ.mm/ha.h.year for an average annual rainfall of 301.4 mm (Table 4). The average annual variation of the erosivity factor (R) shows that the hydrological year 2002/2003 is the most erosive with a value of around 1300.55 MJ.mm/ha.h.yr, while the hydrological year 2007/2008 is the least erosive with 106.06 MJ.mm/ha.h.yr; the corresponding rainfall is respectively 564.5 mm and 119 mm. Indeed, periods of high rainfall aggressiveness are at high risk of erosion. In our study, the rainfall erosivity is considered as constant for the whole studied catchment area, which means that we do not use a layer of this factor under a GIS, but we consider a single value which corresponds to the annual average erosivity during the considered period (1987-2012).

4.2 The soil erodibility factor (K)

Figure 4 shows the spatial distribution of the different K-factor classes in the catchment. The K_{SI} values vary between 0.036 and 0.050 [t.ha.h/ha.Mj.mm]. They cover two erodibility classes according to the USDA classification (Zante et collinet, 2001). Indeed, raw mineral soils and complex soils are represented by the low erodibility class (0.042-0.050), covering more than 84% of the total area (Table 5).

4.3 The topographic factor (LS)

The values of the LS index vary between 0 and 16.94. The map reading generally reflects the topography of the site. The minimum values are spread over the whole area and are generally located in the centre of the study area. The highest values coincide with areas of high altitude or steep slopes at Jebel Bou Rokba, Jebel El Magséme and Jebel As Satour, where the concentration of runoff is highest (Fig. 5). These values are good indicators of soil erosion in this catchment.

4.4 The cover management factor (C)

The resulting C-factor map (Fig. 6) shows that 47% of the catchment has very low vegetation cover and only 53% of the area is well protected. Indeed, the areas most vulnerable to erosion are attributed to the occupation types of degraded rangelands and cultivated areas. In the Sahbi River watershed, there are six land use types with C values ranging from 0.5 for olive groves to 0.01 for forested land (Table 6).

Table 4. Annual precipitation (mm) and average R-value for the period 1987-2012

Hydrological Year	Rainfall (mm)	R(MJ mm ha^{-1} h^{-1} yr $^{-1}$)	Hydrological Year	Rainfall (mm)	R(MJ mm ha-1 h^{-1} yr $^{-1}$)
1987/1988	225.1	295.99	2000/2001	247.5	344.83
1988/1989	269.8	396.21	2001/2002	243.5	335.90
1989/1990	526.4	1162.16	2002/2003	564.5	1300.55
1990/1991	209.6	263.87	2003/2004	306.6	486.77
1991/1992	433.0	848.58	2004/2005	477.5	993.33
1992/1993	191.3	229.19	2005/2006	250.0	350.45
1993/1994	216.0	277.58	2006/2007	304.0	480.15
1994/1995	336.5	565.45	2007/2008	119.0	106.07
1995/1996	250.8	352.26	2008/2009	205.5	255.61
1996/1997	370.0	658.80	2009/2010	141.0	139.38
1997/1998	323.0	529.37	2010/2011	466.3	956.09
1998/1999	396.2	735.51	2011/2012	330.5	549.30
1999/2000	131.5	124.57	***Average***	***301.4***	***473.55***

Table 5. Factor erodibility its soils K adopted for the Sahbi River watershed

Soil units	(ksi)	Area (ha)	Area (%)
Raw mineral soils	0.042	507.5	58.3
Complex soils	0.050	342.3	26.9
Poorlydeveloped soils	0.036	20.2	2.3

Table 6. Factor C Values by Soil Type

Type of land occupation	Factor C	Area (ha)	Area (%)
Cereals	0.4	46.11	5.3
Olives	0.5	30.45	3.5
Forest	0.01	199.92	22.98
Range lands	0.20	331.47	38.1
Scrublands	0.25	120.5	13.85
Clear scrubland	0.30	141.55	16.27

Table 7. Distribution of soil loss classes

N° of class	**Soil loss (t/ha/yr)**	Soil loss classes	Area (%)	**Area (ha)**
1	0-4	Very Low	87.94	765.08
2	4-14	Low	8.48	73.78
3	14-33	Moderate	2.86	24.88
4	33-67	High	0.66	5.74
5	> 67	Very high	0.06	0.52

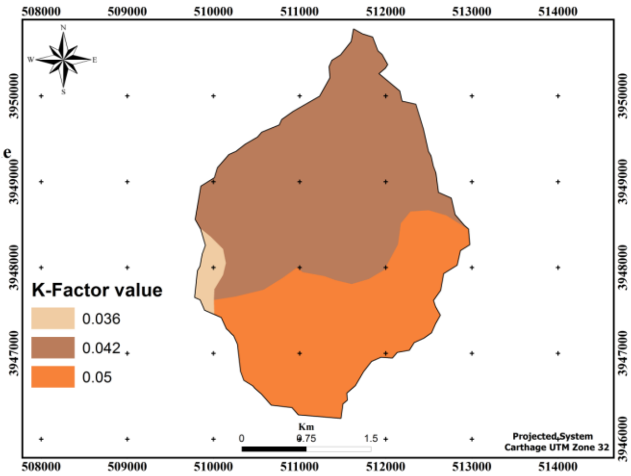

Fig. 4 Soil erodibility map (K) in the Sahbi River watershed

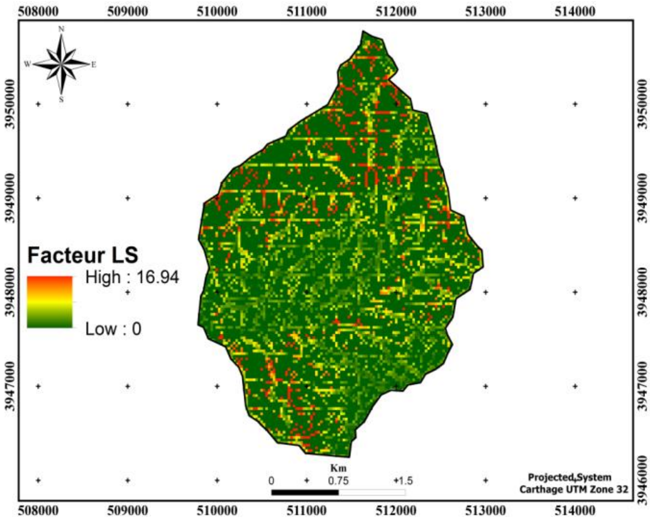

Fig. 5 Map of the topographic factor (LS) in the Sahbi River watershed

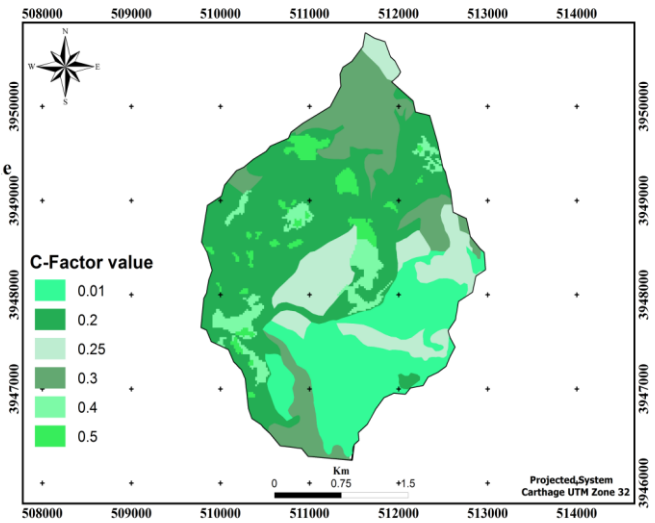

Fig. 6 Map of factor (C) in the Sahbi River watershed

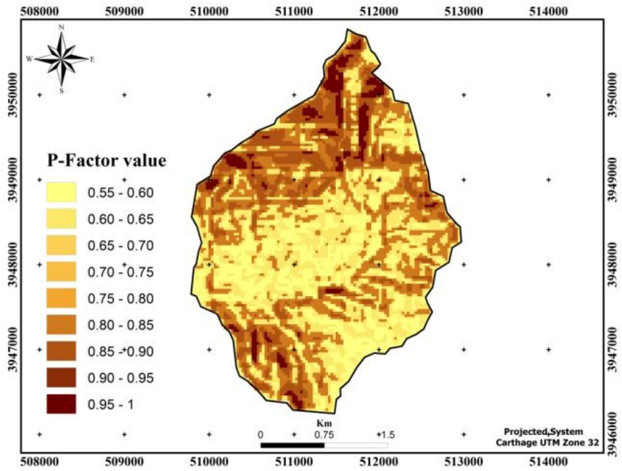

Fig. 7 Map of the anti-erosion factor (P) in the Sahbi River watershed

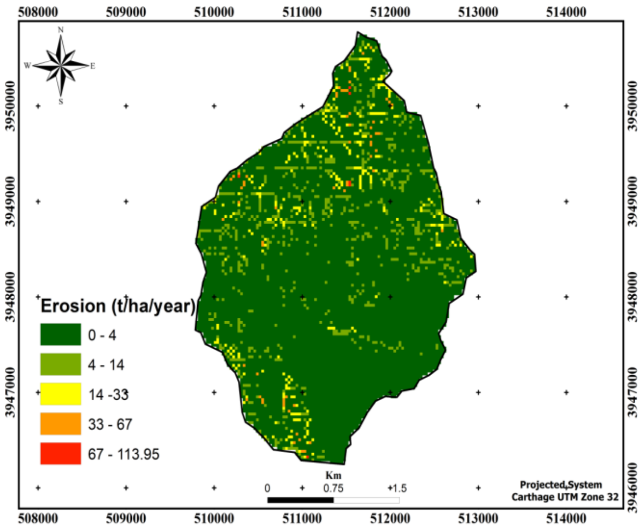

Fig. 8 Soil loss map determined by the RUSLE model in the Sahbi River watershed

4.5 The conservation support practice factor (P)

In this study, the lowest and average P-factor values are attributed to areas with low to moderate slopes. The P-factor generally varies in our case between 0.55-0.6 for the low slope areas, and for the steep slopes the coefficient varies between 0.8 and 1. The latter are mainly located on the reliefs of Jebel Bou Rokba, Jebel El Magséme and Jebel As Satour (Fig. 7).

4.6 Evaluation of soil losses

The crossing of these factors was done at the pixel scale of 30m×30 m, in order to develop a soil loss map at the scale of the Sahbi River watershed. From this figure, it can be seen that the rate of erosion differs from one area to another according to the influence of the different factors that control erosion: this rate varies from 0 to

113.95t/ha/year (Fig. 8). These values obtained (t/ha/year) have been grouped into 5 classes (Table 7):

- A first class that includes areas with very low erosion of less than 4t/ha/year. It makes up 87.94 % of the surface area of the basin studied and is dispersed throughout the area, mainly on the right bank of the watershed.
- A second class which groups together areas with low erosion between 4 and 14 t/ha/year. It constitutes 8.48 % of the surface area of the basin studied and focuses mainly on the plain in the middle and upstream of the watershed.
- A third class which groups together areas with moderate erosion between 14 and 33t/ha/year. It represents 2.86 % of the surface area of the basin studied and covers mainly the sectors located on the plain downstream and north of the watershed.
- And the last classes, a fourth which groups together areas with high erosion between 33 and 67t/ha/year. It represents 0.66 % of the surface area of the basin studied, and a fifth class which groups together areas with erosion greater than 67t/ha/year. It represents 0.06 % of the surface area of the basin studied. They focus on the mountainous areas respectively in Jebel Bou Rokba, Jebel El Magséme and Jebel As Satour and on the areas with friable soil or highly degraded vegetation and agricultural areas coinciding with the two banks of the watershed.

The dominant class of soil losses (0-4 t/ha/yr) estimated in this basin are below the limit of 12.5 t/ha/yr, considered as a tolerance threshold (Cormary and Masson, 1964), occupying about 88% of the total area.

For comparison, these results are close to those obtained in the Ayda River watershed (North-West of Tunisia), where the erosion rate varies from 0 to 189 t/ha/year (Chafai et al., 2020), with low losses (9 t/ ha/year), covering 92.45% of the total area and on the Siliana dam basin (Chabaan, 2016), which shows erosion (0 to more than 100 t/ha/year), with low losses (7 tons/ ha/year) covering 70% of its area.

5. Conclusion

The quantification of soil losses in the study area was carried out using the Revised Universal Soil Loss Equation (RUSLE) integrated in a Geographic Information System. The method used, despite its limitations, provides important assistance to decision-makers in targeting vulnerable areas and planning erosion control interventions.

The results obtained show that the soils of the Sahbi River watershed are affected by several factors that favour erosion, namely the steepness of the slopes, the low vegetation cover and the erodibility of the soil. The erosion map showed that the risk does not appear homogeneously over the whole catchment area, it is qualified as very low (0 - 4 t/ha/year) over an area of 764.7 ha, that is 87.9%. In the remaining 3.5%, the risk of erosion appears to be more problematic, classified as medium to very high. The areas with high erosion are mainly focused on the mountainous areas respectively in Jebel Bou Rokba, Jebel El Magséme and Jebel As Satour. His situation is favoured by erosion factors that combine to accelerate erosion, steep slopes (25% of the surface of the Sahbi River watershed has slopes greater than 15%), degraded vegetation cover (47% of the surface is unprotected) and highly erodible soils (84% of the soils show a K_{SI} factor > 0.042).

Finally, the RUSLE model does not take into account other types of erosion other than sheet erosion, but only estimates average losses caused by surface erosion. It is based on data for very small watersheds, so there will be problems of scale if we want to predict regional erosion values.

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