JOURNAL | AGRI & BIOTECH
OF NEW SCIENCES
WWW.JNSCIENCES.ORG

Water Erosion modeling in a Mediterranean semi-arid catchment using USLE/GIS (El Gouazine, Central Tunisia)

A. BEN RHOUMA*[1], T. HERMASSI[2], H. HABAIEB[2]

[1] National agronomy institute of Tunis, 43 Avenue Charles Nicolle, Tunis, 1082 Tunisie

[2] National institute of Rural, Water and Forest engineering, Rue Hedi Karray 2080 Ariana, Tunisie

*Corresponding author: aidabenrhouma@live.fr

Abstract – This study is a research for an effective methodology for water erosion modeling. Indeed, understanding and predicting the effects of this natural phenomenon, is the most difficult for the semi-arid Mediterranean climate due to its climatic irregularity and its soils fragility. USLE model (Universal soil loss equation) estimates soil erosion losses, and makes it easy to decide about what conservation measure we should adopt. USLE was selected because it is the simplest approach while remaining robust, and it solves the problem of data availability. The USLE method is able to simulate the erosive pattern with the possibility of creating several scenarios. For our study case, we found that the majority of the watershed surface shows a low to medium erosion rate, and that the severe erosion rates are located in steep-slope areas and on agricultural land intended for cereals.

Keywords: Erosion sensitivity, Universal soil loss equation, GIS tools.

1. Introduction

The Mediterranean region is among the regions that are the most affected by Water Erosion in the world; this high risk is caused by several factors, but mainly by the great seasonal variability of the Mediterranean climate, the fragility of the soils, the great anthropogenic pressure, the inappropriate land use and the vulnerable land cover patterns. Moreover, climate change further accentuates the effects of erosive behavior. Many erosion indicators have been identified in this region and they have shown that the danger can be irreversible, so modeling this natural phenomenon seems to be the best way to predict its danger and fix the appropriate ways to fight against it. These empirical methods are reliable but they need many complex data, wish is the major weakness. The erosion models can be classified within several criteria; parametric models and deterministic models. In another way, by choosing the formalisms of the simulated processes, we can have another classification: physical based models and empirical models (Gumiere, 2009). The choice between all those types should be made according to the purpose of the study and the type of dominant erosive processes. One of the most widely applied empirical models for assessing the sheet and rill erosion is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith in 1978. This model takes into consideration several determining factors, such as the soil erodibility factor, rainfall erosivity factor, slope length and steepness factor, cover and management factor and water and soil conservation practices factor. This approach was already used in many region of the Mediterranean basin: the Batta watershed in Siliana Tunisia (Kefi, 2009), in the catchment of Mrichet and Saadine in Tunisia (Andersson, 2010), in Chalkidiki Greece (Gitas, 2009), in the Oum Erbiaa Watershed in Morocoo (Yjjou, 20014

2. Material and Methods
2.1. The study area

Our study area is located in Tunisia and called El Gouazine (35°42'15'', 9°42'15''). This watershed of 1810 ha surface belongs to the delegation of El Oueslatia of the governorate of Kairouan. The watershed drains into the hills lake of El Gouazine built in 1990 at the outlet of the watershed with an initial storage capacity of 233,370 m³. The average annual rainfall of 400 mm and the annual evapotranspiration of 1680 mm are related to a semi-arid climate. The longitudinal average slope of this is 1.8% wich shows that this basin is very elongated and its transverse slope, significantly higher, exceeds 5%. The altitudes of the El Gouazine watershed vary between 390 to 590 m and yet it is considered to be a homogeneous plain, its global slope index Ig does not exceed 18. In fact, more than 60% of the catchment area represents a low slope less than 5%.

BEN RHOUMA et al. (2018) / Journal of new sciences, Agriculture and Biotechnology, 50(7), 3071-3081

3071

Geologically, the formations are characterized by the presence of a marl-limestone substratum in the southeastern part of the watershed and a clay-sandstone substratum in the northwestern part (Nasri and Albergel, 2004).

Figure1. Location of the El Gouazine catchment
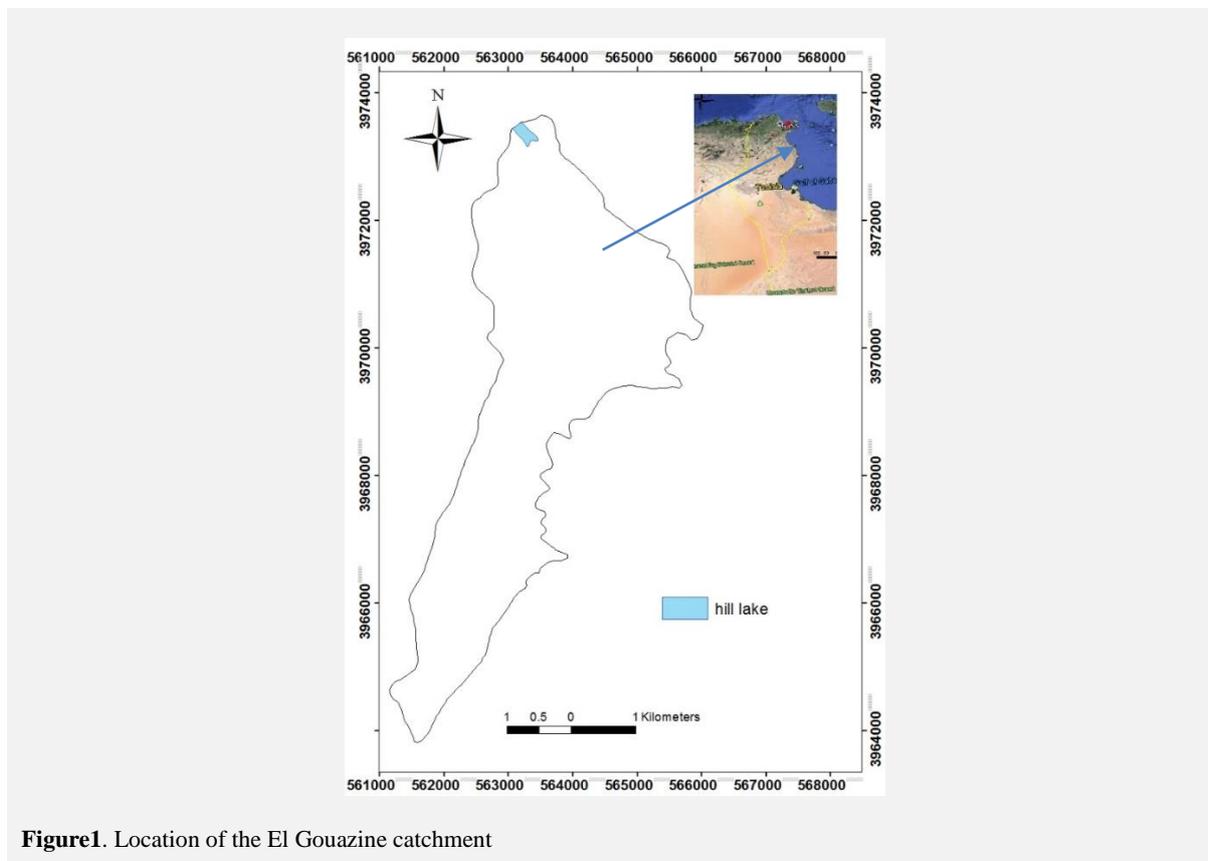
The pedology of the El Gouazine watershed was studied first, by Burnisso (1966) and completed by Zante and Mansouri (1999) (Ayari and *all*, 2004), they found that the pedology of the zone is classified as follows:

- Calcaric Leptosols; Lithic Calcaric Leptosols, soils occupying more than 56% of the area of the zone, they occupy interflows upstream of the catchment and on limestone slabs in the east part.
- Calcaric Cambisols; Leptic (Cambic) Calcisol 8.5% downstream of the encrusted glacis.
- alluvial or colluvial soils, 20%, they are more or less stony often calcimorphic character and little evolved soil erosion 8.5% developed on marl-limestone or downstream rendzines on calcareous crust

The natural vegetation of the area consists of forests and garrigue of Aleppo pine and Carrob trees, they occupy the encrusted heights and limestone outcrops. The Alfa *(Stipa tenascissima)* is found on stony areas. Among the natural species found also in the El Gouazine basin are rosemary (*Rosemarinus officianalis*), *Erica multiflora, Geniste cinens, cistus selvifolius, Cistus libanotis, Phyllarea angustifolia, Artemisia herba alba, Ballota hirsuata.* In another hand, the major soil occupation of the basin is the annual cereal / fallow crop, with some olive groves

2.1.1. Soil and Water Conservation Structures

From June 1996 to July 1997, the Gouazine watershed underwent mechanical terracing over a total area of 783 ha in two successive periods. These benches consist of earth walls with an average height of 1.5 m. This development focused mainly on cropland and some of the degraded rangelands to convert them to cropland they represent about 43% of the total area of the basin. They were terraces with total retention.

2.2. Erosion modelling
2.2.1. The universal soil loss equation (USLE)

The soil loss equation is the result of the analysis of 10000 annual measurements of erosion carried out over 20 years of observation on experimental plots, in 46 stations in the United States. These experimental plots (22.1 m long and 9% slope) collected data on runoff and soil loss. Between 1947 and 1948, Smith and Witt developed an equation to estimate erosion in the Missouri taking into account slope, slope length, crop rotation, land conservation practices and soil type (Délusca, 1998). In 1958, Wishmeier introduced the universal equation of soil loss. This equation makes it possible to calculate the surface erosion (sheet and rill erosion), it is written in the following form:

$$A = R * K * L\ S * C * P$$

A = soil loss (t / ha / year), R = rainfall erosivity, K = soil erodibility, LS = topographic factor, C = cultural coefficient, P = conservation and management factor

The geographic information system plays the role of integrator of the data necessary for the estimation of erosion. First, basic data (maps, climatological data, and satellite images) are analyzed and manipulated in the GIS, to obtain distributed information, which provides the main factors of the USLE for each cell of the site. These factors are then overlaid in the USLE/GIS according to their spatial distribution, to estimate erosion. Indeed, each factor, is presented by a thematic map (layer) in raster format. These maps are then combined to produce an erosion map.
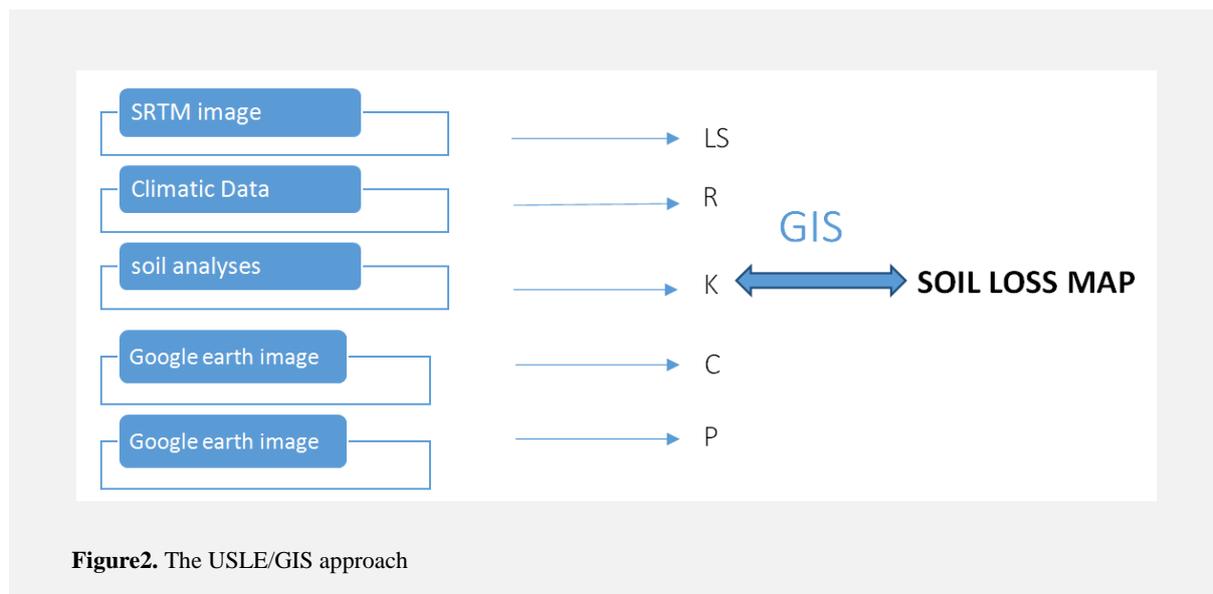
Figure2. The USLE/GIS approach

- **R-factor calculation**.

This factor represents the erosive potential of rainfall. To obtain this factor, the following relationship (Arnoldus, 1980), which is based on monthly and the annual rainfall data, is used (Kefi, 2009).

$$Fm = \sum_{i}^{12} \frac{Pi^2}{P}$$

P_i= average Monthly precipitation, P= Average annual precipitation, the unit of this parameter is MJ mm/ha/ h/ an
The rainfall erosivity factor was considered constant over the entire catchment area.

- **K-factor calculation**

The k-factor (soil erodibility factor) depends on the following soil parameters in combination: Percentage of silt, very fine sand, clay and organic matter, structure (codes between 1 and 4 are given to different common structures). Drainage (codes between 1 and 6 are given from fast to very slow drainage respectively). The K Factor equation of Wishmeier is:

$$K = 2.8 10^{-7} * M^{1.14} * (12 - MO) + 0.0043(b - 2) + 0.0033(c - 3)$$

M = granulometric factor = (% silt +% very fine sand) (100 -% clay), MO = organic matter (%), b = soil structure code (very fine granular: 1, fine granular: 2, medium granular and coarse: 3, in blok or massive: 4), c = code of permeability class (fast: 1, moderate to fast: 2, moderate: 3, slow to moderate: 4, slow: 5, very slow: 6). The unit of this factor is t.ha / ha.MJ.mm.

- **LS factor calculation**

The LS factor is the combination of slope length and slope, the topography of the El Gouazine watershed is relatively moderate to low so the LS value varies between 0 and 38.76.

$$LS = L = \left(\frac{\Lambda}{221}\right)^{m} * (65.41 * \sin^2\theta + 4.56 sin\theta + 0.065)$$

m = exponent which depends on the degree of slope: m = 0.5 if $\theta \geq$ 5 %, m = 0.4 if $3.5 \leq \theta <$ 5 %, m = 0.2 if $\theta <$ 1 %., Λ = linear length of the slope, θ is the angle of the slope in percentage. (Cormary and Masson, 1964).

- **C factor calculation**

The C-factor represents how management affects soil loss. It is mainly related to the vegetation's cover percentage and it is defined as the ratio of soil loss from specific crops to the equivalent loss from tilled, bare test-plots. The value of C depends on vegetation type, stage of growth and cover percentage (Gitas, 2009). For the Tunisian context, Cormary and Masson were able to define the value of this factor for different plant covers (Cormary and Masson, 1964).

Table1. C factor in Tunisia

Vegetation cover	Average annual C factor
Bare ground, fallow	1
Fruit arboriculture	0.9
Winter wheat	0.7
Cereal rotation	0.4
forage crops	0.2
Improved pasture	0.01
Vine and orchard	0.9
Ordinary pasture	0.15
Reforestation	0.15
Degraded forest	0.05
Dense forest or pasture	0.01

- **P-factor calculation**

The support practice factor P represents the effects of those practices that help prevent soil from eroding by reducing the rate of water runoff. The values of P were calculated as rates of soil loss caused by a specific support practice divided by the soil loss caused by row farming up and down the slope (Gitas, 2009). According to Wishmeier, this factor is strongly influenced by the topography; it is thus expressed according to the slope (Roose, 1999).

Table2. P factor for the Tunisian context

Slope (%)	Contour culture	Alternate bands culture	terraces (the soil deposited in the canal is considered as lost)	terraces(the soil deposited in the canal is not considered as lost)
1.1 to 2	60	30	60	30
2.1 to 7	50	25	50	25
7.1 to 12	60	30	60	30
12.1 to 18	80	40	80	40
18.1 to 24	90	45	90	40

3. Result and Discussion

All the maps needed to obtain the soil loss map should be in the raster format, after that is necessary to cross the maps of the various factors via the application raster calculator of ARCGIS. The version used in this study is the 10.2. Indeed each pixel that represents the basic unit of the map contains information on each factor of the formula. By multiplying the factors, actually we multiplies the information contained in each pixel of the different maps. Finally, the erosion maps gave each individual cell's a value of soil erosion risk. The first factor calculated were the R Factor, We have then calculated an average value for the 14 years of the available climatic data from 1994 to 2007. For the second factor, the soil erodibility factor, soil samples were taken, and analyzed, to determine all the parameters needed in the equation (percentage of silt, sand, clay and organic matter). The location of the samples points is shown by the map below (figure 3. a). By an IDW (*Inverse distance weighted)* GIS interpolation, we have obtained the K factor Map (figure 3. b).

(a)   (b)

Figure3. (a) Map of the spatial distribution of sampling points for the K factor for the El Gouazine basin; (b) map of the spatial distribution of the erodibility factor K (USLE) of the EL Gouazine basin in (t.ha / ha.MJ.mm)
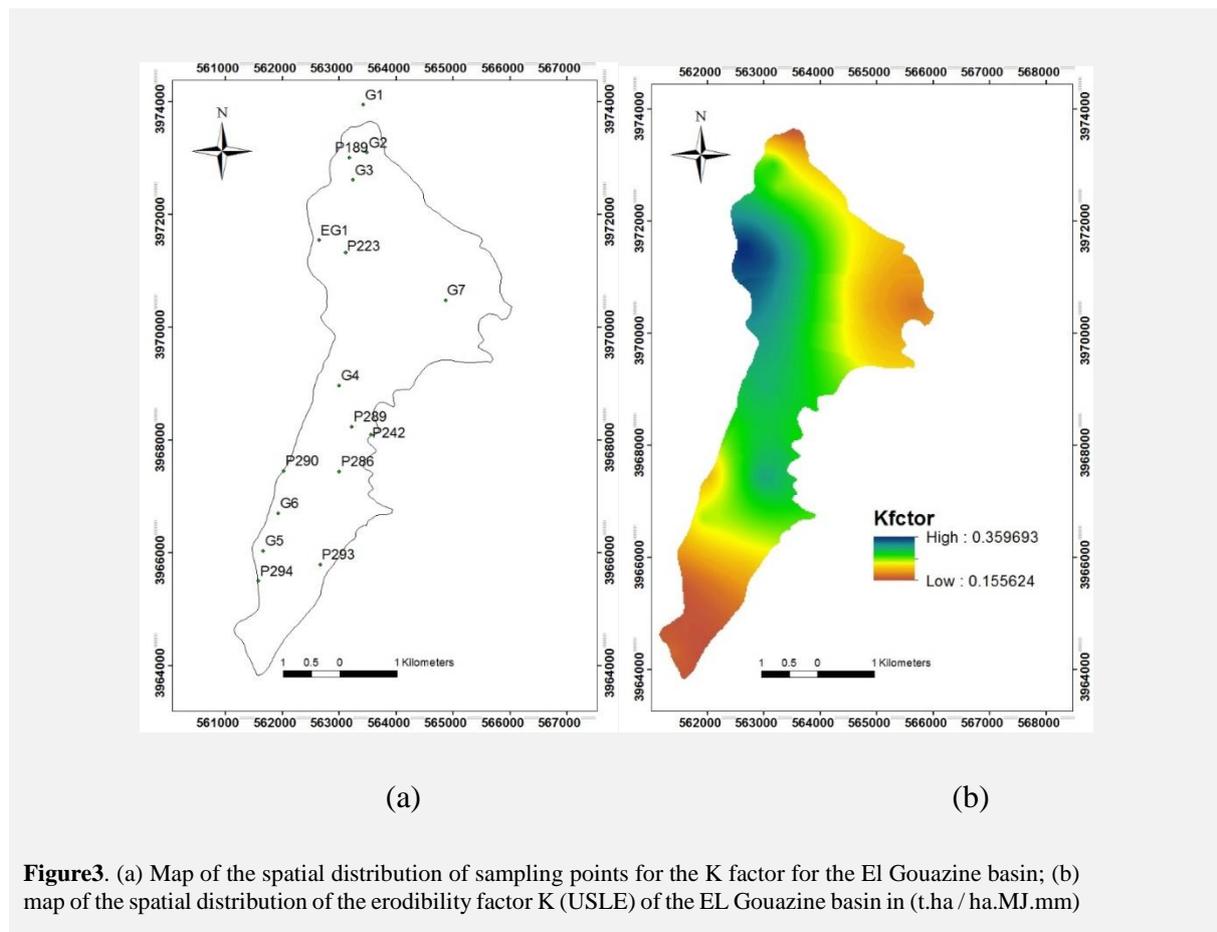
For the Ls factor, we have used the ILWIS software which is a geographic information system, and for that we used the SRTM (Shutter Radar topographic mission) of the watershed (figure 4):
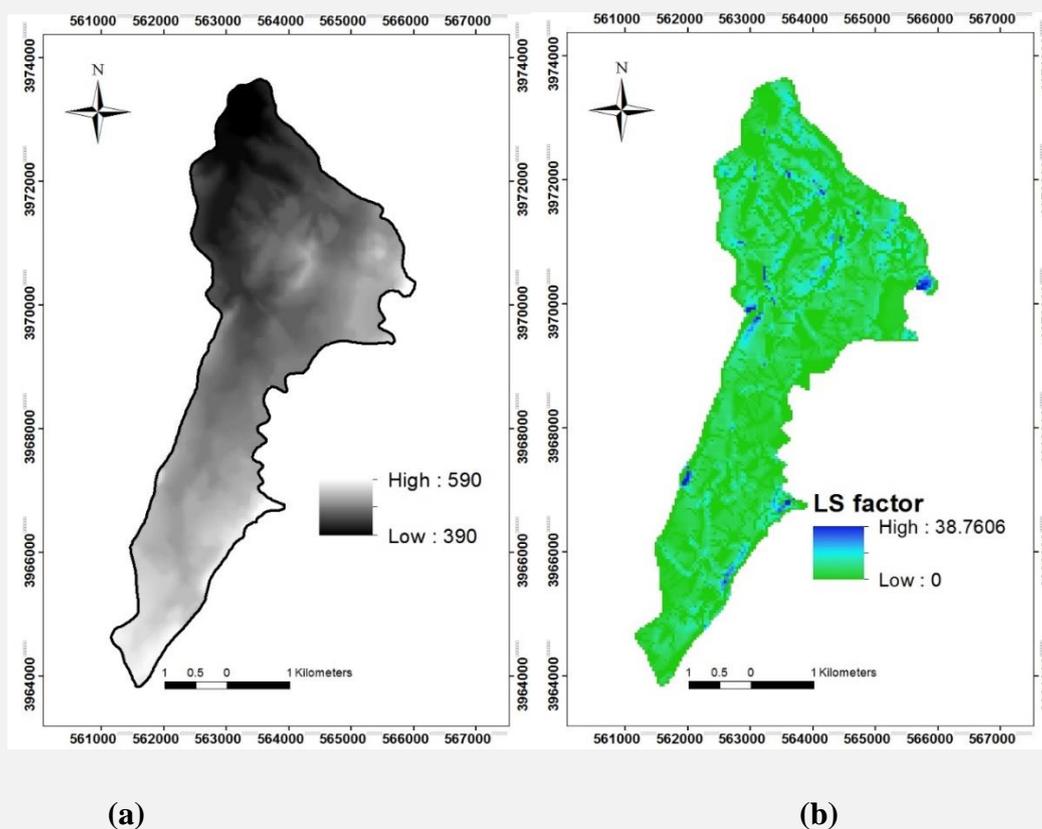
Figure4. (a) SRTM (Shutter radar topography mission); (b) LS factor map

Finally, for the last two factors, C and P factors, we used the Google earth image of the year 2015. The vegetation map was used to assign a C value for each land cover as shown by the table below:

Table3. Factor C corresponding to each soil occupation for the El Gouazine basin

Vegetation cover	C factor	% per surface
Alfa	0.15	15 %
Arboriculture and cereal	0.9	0.3 %
Arboriculture	0.9	6 %
wheat	0.7	32 %
Degraded forest	0.05	12 %
Dense forest	0.01	11.8 %
scrubland	0.05	13.2 %
Pasture	0.15	19.6 %

The interaction between plant cover and cultivation techniques varies between 0.7 for annual crops and 0.01 for dense forests (figure 5). As we can see from the table (table 3), the main vegetation cover is Wheat with 32% of the total surface, with a C value of 0.7. This distribution has a great effect on the resulting soil map.
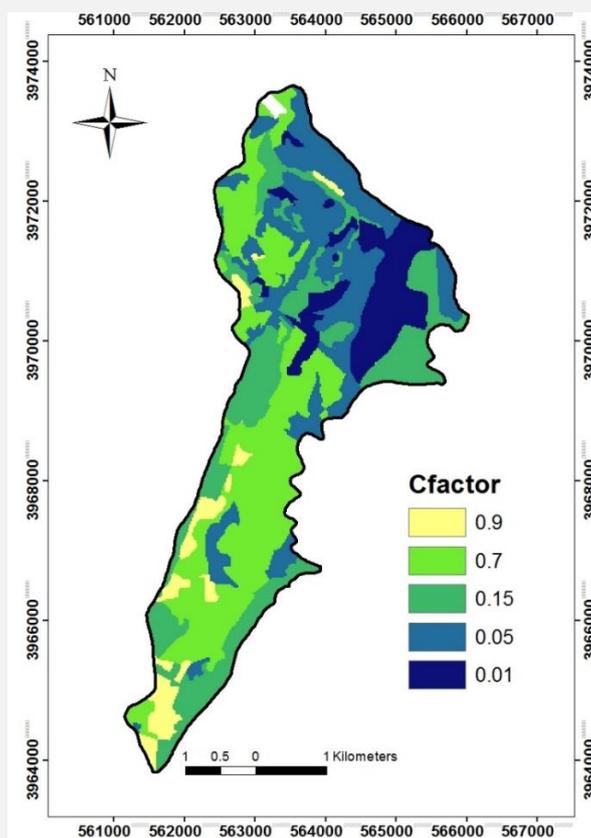
Figure5. C factor map

As well , the P factor Map was built as shown by the next table :

Table 4. Distribution of the factor P

P factor	%Surface
1	57 %
0.6	13 %
0.8	1 %
0.5	28 %

The value 1 refers to regions without conservation measures, we can say that approximately half the surface of the watershed is covered with terraces. The next figure (figure 6) is a spatial distribution of this factor:
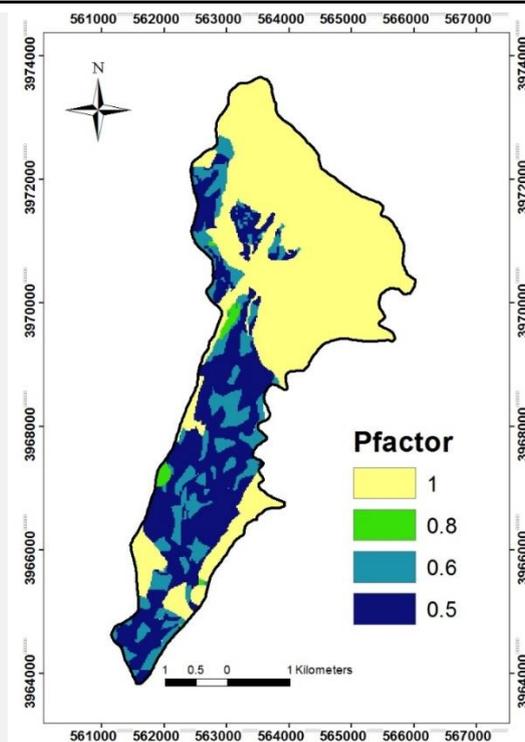
Figure 6. P factor map

After crossing all these factors, the resulting map (figure 7) was classified in 5 classes of erosion, in order to obtain a better view and understanding, and at the same time, be able to compare areas. These values were finally presented in a color scheme of brown,the size of the cell in the map is 30*30 m. So
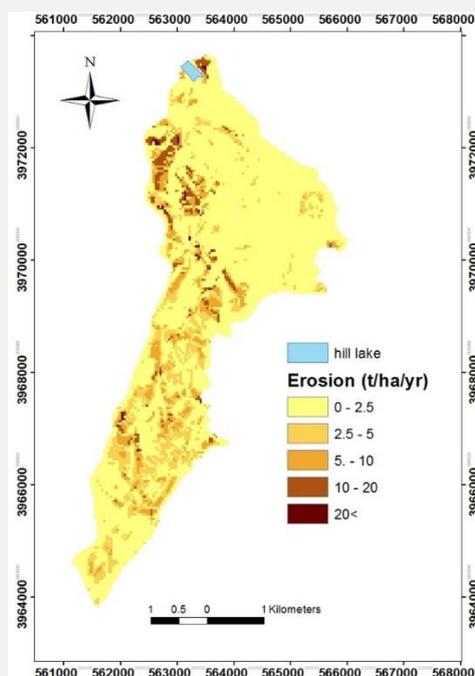
Figure7. Soil loss map determined by the USLE model

The erosion map shows that the average loss of water erosion for the El Gouazine basin is 1.9 t/ha/yr and the total losses are 20879 t/year. This result shows that El Gouazine watershed has a low erosion rate due to its low LS factor and because a large part of the watershed is covered by forest which is a substantive factor in intercepting rainfall hence declining the effect of erosion. The same conclusion was made by (Kefi, 2009) who studied USLE erosion modeling in the Koukat watershed in Kairouan governorate. The next table (table 5) represents the spatial distribution of different classes of erosion:

Table 5. Distribution of the water erosion classes per total area for the El Gouazine basin

Soil loss (t/ha/an)	% surface
0-2.5	68 %
2.5-5	10 %
5-10	13 %
10-20	7.5 %
20>	1.5 %

The analysis of the erosion map shows that, just like the result of (Gaubi 2017) in the Lebna watershed, the severe erosions exceeding 20 t/ha/year are found in steep-slope areas and on agricultural land intended for cereals. On the other hand, the Northeast forest part has a low rate not exceeding 5 t/ha/year. If we take in consideration the soils type, we can notice that the regions with high rate of erosion are those with calcaric rendzines, Marly soils and soils with erosive origin. These soils are those with the highest Kfactor values.

3.1. Land use change scenarios
The USLE model has the advantage of being able to predict the erosive behavior according to several scenarios by modifying the various parameters of the equation. The choice was made to modify the land use map by increasing the forest area from 201 ha initially to 429 ha. In the same way we changed the cereal in monoculture way with cereal in rotation way, this modification allowed us to have the following result:
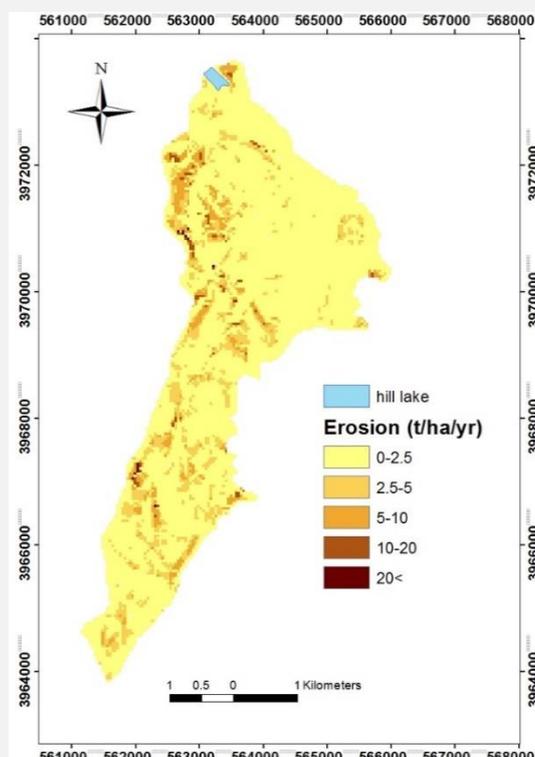
Figure 8. Map of soil loss of the Gouazine watershed after the modification of the land use

The new map (figure 8) showed a decrease in average erosion that went from 1.9 t/ha/yr to 1.2 t/ha/yr, so the total erosion decreases to attend 12997 t/yr. The spatial distribution of the different classes of erosion is shown in the table below (table 6):

Table6. Distribution of the water erosion classes per total area for the El Gouazine basin

Erosion classes (t/ha/yr)	% per total surface
0-2.5	86.2 %
2.5-5	9.5 %
5-10	3.5 %
10-20	0.6 %
20>	0.1 %

The weak erosion class remains predominant compared to the other classes with a percentage of 86.2%, this represents an increase of 18 % compared to the real state. We also notice a significant regression of the moderate to severe erosion classes to 31 %. This result attest the huge impact of the land cover on the soil protection. In fact, a dense vegetation helps reducing the kinematic energy of the runoff, so the infiltration rate increases and the erosion is substantially reduced. This methodology is a great tool for decision support, it helps to target the action to be undertaken for prevention or rehabilitation according to the severity of the degradation.

4. Conclusion

The quantitative assessment of spatial soil erosion is a valuable information to control the erosion, so using a non-data-demanding model such as the USLE seems to be a good way to predict the erosive behavior in the watershed scale.

The Empirical Soil Loss Assessment (USLE) model was integrated into the ARCGIS Geographic Information System, which allowed the manipulation of several criteria and parameters. The evaluation of the losses in soil made it possible to highlight a classification of the surfaces according to the importance of risk to the erosion. The zoning of this map, especially, which of areas with higher erosion rates, will facilitate intervention decisions and the choice and conservation measures planning. The main results found within this study are that the majority of the watershed surface suffers from low to medium erosion rate 78%, and that the highest erosion rate exceeding 20 t/ha/yr are is found in steep-slope areas and on agricultural land intended for cereals. We have also proved the great effect of the land cover on maintaining the soil by the reduction of the speed of the runoff. This last result was clearly shown by the scenario of the increase of the forest surface.

5. References

Ayari H, Baccari N, Ben Younes M, Collinet J, Debabria A, Pepin Y, Zante P (2004) Bassin versant Gouazine caractéristiques générales du milieu physique. p 43

Andersson L (2010) Soil Loss Estimation Based on the USLE/GIS Approach through Small Catchments, Avdelningen för Teknisk Vattenresurslära, TVVR-10/5019.

Cormary Y and Masson J(1964) Etude de conservation des eaux et du sol au centre de recherche du génie rurale de Tunisie : application à un projet –type de la formule de perte de sols de Wishmeier. Cahier ORSTOM. Série Pédologie, 2 (3) 3-26

Delusca K (1998) Estimation de l'érosion hydrique des sols à l'aide de l'Équation Universelle de Perte de Sol assistée d'un Système d'Information Géographique : Le cas du bassin versant de la ravine Balan Haiti. Thèse de doctorat. Université de Montcon Canada

Gumiere SJ(2009) Thèse de doctorat Contribution à la modélisation déterministe spatialisée de l'érosion hydrique des sols à l'échelle des petits bassins versants cultivés. Université SupAgro p228

Gitas I (2009) Multi temporal soil erosion risk assessment in N Chalkidiki Using a modified USLE raster model, EARSEL EProceedings. 8.1.

Gaubi I, Chaabani A, Ben Mammou A, Hamza M H (2017) A GIS-based soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) (Lebna watershed, Cap Bon, Tunisia). Nat Hazards 86:219-239. DOI: 10.1007/s11069-016-2684-3

Kefi M, Yoshino K, Zayani K, Isoda K (2009) Estimation of Soil Loss by Using Combination of Erosion Model and GIS -Case of Study Watersheds in Tunisia. Journal of arid land studies 19-1 287- 290

Mansouri T, Albergel J, Séguis L (2001) modélisation hydrologique spatialisée de petits bassins versant en contexte semi-arides méditerranéen. Hydrologie des régions méditerranéennes. Montpellier (FRA) : UNESCO IRD : 225-236.

Nasri S et Albergel J (2004) impact des banquettes sur le ruissellement d'un petit bassin versant. Revue des sciences de l'eau, 17 (2) : 265–289 : DOI 10.7202/70553ar

Roose E (1999) Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols. Bulletin pédologique de la FAO n°70.

Yjjou M, Bouabid R, El Hamidi A, Essahlaoui A, El Abbasi M (2014) Modélisation de l'érosion hydrique via les SIG et l'équation universelle des pertes en sol au niveau du bassin versant de l'Oum Er-rbia, The International Journal Of Engineering And Science,3 (8) : 83-91