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Potential Erosion Risk Calculation Using Remote Sensing and GIS in Oued El Maleh Watershed, Morocco

Hicham Lahlaoi[1], Hassan Rhinane[1], Atika Hilali[1], Said Lahssini[2], Loubna Khalile[1]

[1]Geosciences Laboratory, Faculty of Sciences Ain Chock, Hassan II University, Casablanca, Morocco
[2]National School of Forestry Engineering, Salé, Morocco
Email: Lahlaoi.hicham@gmail.com

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Abstract

Oued El Maleh watershed is considered the largest ocean basin of the Chaouia-Ouardigha region in Morocco. Severe flooding occurred in 1996, 2001 and 2002 in the watershed. Thus, significant economic and human damage has been caused. The floods of Mohammedia city, located in the outlet of the watershed, were due to the silting of the Oued El Maleh dam which has lost its ability to retain water. This work, therefore, aims to assess soil losses by water erosion in the Oued El Maleh watershed through modeling main factors involved in water erosion. The methodology used is based on the use of the universal soil loss equation (USLE). The model includes the following factors: soil erodibility, the inclination of slopes, the rainfall erosivity, vegetation cover and erosion control practices. The aggressiveness of rainfall was calculated for a number of stations bordering the study area and interpolated across the watershed using geostatistical model. Soil erodibility was extracted from soil map and soil survey. The effect of topography was approached by combining the degree of slope and slope length using a digital elevation model (ASTER) and ArcHydrology extension (ArcGIS). The vegetation cover was derived from Landsat image ETM through the supervised classification method. The index of erosion control practices was approached by field visits. All factors have been measured and integrated into a geographic information system which enabled us to spatialize the degree of sediment production at the watershed scale in a synthetic map. The annual soil loss is 8.21 t/ha/yr and the soil loss classification shows that surfaces affected by high erosion are equivalent to 10% of the watershed. Furthermore, this map is available to support land managers policy makers in the process of decision making related to soil conservation, infrastructure and citizens' property protection.

Keywords

Watershed Oued El Maleh, Erosion, USLE, Geographic Information System

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1. Introduction

Water erosion is a dynamic process of detaching, transporting and depositing soil particles under the effect of the kinetic energy of water. Soil loss causes adverse influences of widespread with different intensities depending on the environment biophysical characteristics and threats human sustainability [1]. The effects of this phenomenon are not limited only to the reduction of agricultural land productivity [2], but they also affect the quantity and quality of available water by accelerating the rate of siltation of reservoirs [3] and reducing the production of electricity [4] [5].

In turkey the erosion rate reaches an average which varies from 500 to 600 million ton/year [6]. In Syria, the soil erosion risk map published by FAO, UNEP and UNESCO in 1980 indicated losses values ranging between 50 and 200 t/ha/yr. In Lebanon, the estimates reported figures ranging from 50 to 70 t/ha/yr in the mountains of Lebanon and Anti-Lebanon (FAO, 1986). In Tunisia, 45% of the land area is threatened by erosion [7]. In Algeria, 45% of Tellian areas, equivalent to 12 million hectares, are threatened [8].

In Morocco, 40% of land is affected by water erosion [9]. In some parts of the Rif in northern Morocco, erosion rates sometimes reach 30 to 60 t/ha/yr [10] [11] and get to 2000 t/km^2/yr for the central and western Rif [12]. In the Middle and High Atlas the annual averages ranged from 500 to 1000 t/km^2/year and from 1000 to 2000 t/km^2/yr in the Pre-Rif and the Mediterranean border. Therefore, dams lose their water storage initial capacity due to their siltation which is estimated at 0.5% by year [13]. The largest Moroccan dams receive each year approximately 50 million tonnes of sediment [14], which affects their storage capacity and brings about an annual loss of almost 300 million Dirhams [15].

In the watershed of Oued El Maleh scale, the erosion is manifested in different forms and it's accentuated by the degradation of Mdakra and Achach forests. In fact, the local population subsistence depends on forest products (wood, firewood, grazing…) and agriculture [16]. This anthropogenic pressure on natural resources increases the land vulnerability to erosion.

In this area, where floods are important, the construction of the recent dam Tamesna located upstream needs protection to combat siltation. The objective of this work is to study the vulnerability of watershed erosion through the use of empirical model USLE [17]. It is organized into three sections: 1) materials and methods with the presentation of the study area and the main factors involved in the model (these were evaluated by field investigations associated with the use of remote sensing and/or derived by the use of GIS); 2) section results relating the implementation of the model and 3) discussions and conclusions section.

2. Materials and Methods

2.1. Presentation of the Study Area

Oued El Maleh watershed is located in the regions of Chaouia Ouardiga. It extends on provinces of Mohammedia, Settat, Benslimane and Khouribga, between 32˚90 N - 33˚76 N lalitude and 06˚60 E - 07˚50 E longitude. It's bounded on the North-east by Oued Nfifikh watershed and by oceanic bassins of Chaouia on the south-west (**Figure 1**). It covers an approximate area of 2577 km^2. It is the catchment area drained by the Oued Mellah and its affluents Oued hassar, oued Zamra, oued Laatach and whose outlet is located at the city of Mohammedia (**Figure 2**).

The bioclimate is semi-arid with a rainfall annual average of 320 mm. the altitude is ranging from 0 to 962 meters. Geologically, the area is still characterized by large outcrops of Triassic series of red clay. Several soils types were identified, mainly vertisoils, fersialitics, calcimagnesics and poorly evolved soils.

2.2. Data Used

The data used in this study include land use, digital elevation model (DEM), rainfall data and soil data. The land use was extracted from Landsat image Enhanced Thematic Mapper (ETM) acquired on December 16, 2014 with a spatial resolution of 30 m and projected in Universal Transverse Mercator (UTM). The digital elevation model (DEM) was extracted for the study area from ASTER Global Digital Elevation Model (ASTER GDEM) with spatial resolution of 30 m. The rainfall data for 30 years were collected from Hydraulic Basin Agency of Bouregreg and Chaouia over 12 climatic stations. The pedology data were provided by the National Institute for Agricultural Research of Settat.

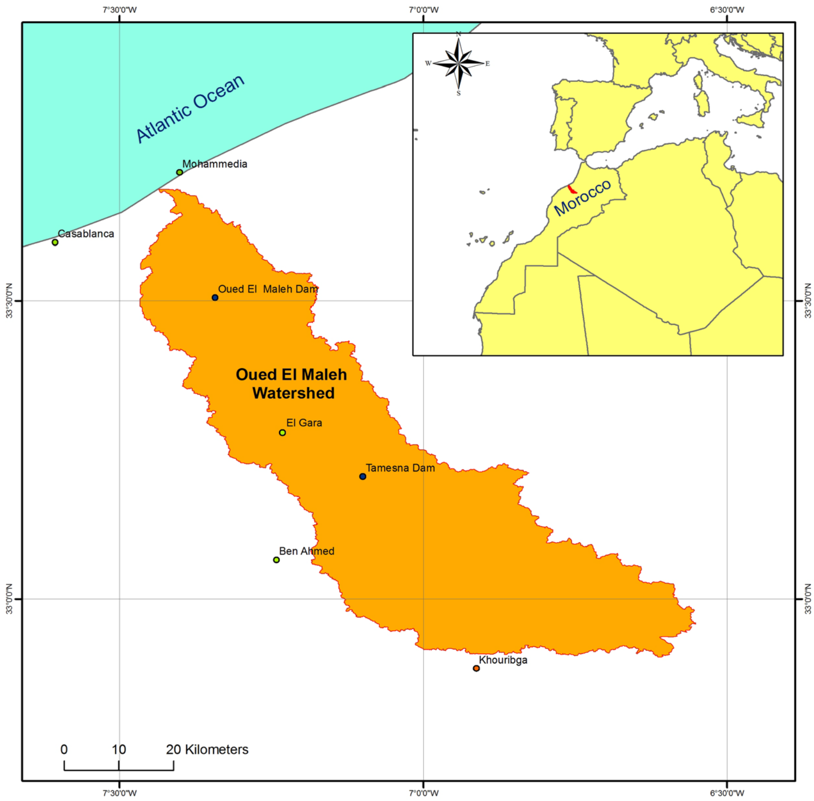

Figure 1. Situation of Oued El Maleh watershed.

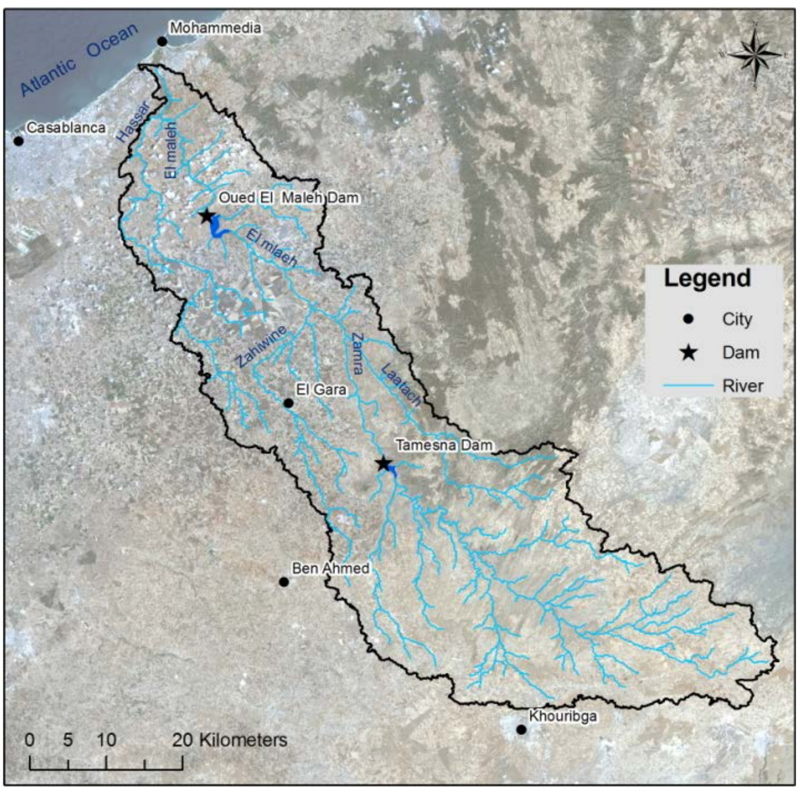

Figure 2. Hydrographic network of Oued El Maleh watershed.

2.3. Used Model and Methodology

Different approaches have been used to assess the soil erosion risk, including empirical erosion models [18] [19], a ranking method based on selected indicators such as percentage of bare ground, aggregate stability, organic carbon, percentage clay, and bulk density [20] and qualitative erosion risk mapping based on the combination of five factors namely geology, soil, relief, climate and vegetation [21]. The most widely used model is the USLE [22] expressed as follows:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where: A is the soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$). R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$). K is the soil erodibility factor ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$). LS is the slope steepness and slope length factor (dimensionless). C is the vegetation cover factor (dimensionless). P is the conservation practice factor (dimensionless).

2.3.1. Rainfall Erosivity Factor (R)

The original equation of (R) uses the kinetic energy of the rain and requires measurements of rainfall intensity (Wischmeier & Smith, 1978):

$$R = K\ Ec\ I30 \tag{2}$$

This direct method of Wischmeier and Smith can only be applied in areas equipped with autographic recorders. An alternative formula developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980) [23] involves only annual and monthly precipitation to determine the R factor.

$$R = 1.735 \times 10^{1.5 \cdot \log \Sigma\left(pi^2/P\right) - 0.8188} \tag{3}$$

The annual and monthly precipitation was recovered from 12 weather stations for 30 years. R values were calculated for the selected stations (**Table 1**). They were interpolated over the whole watershed using geostatistic model (kriging).

2.3.2. Soil Erodibility Factor (K)

The soil erodibility factor K represents the susceptibility of soil particles to be detached. It's related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas [24]. K values were derived using the wischmeier nomograph [25] for survey soil analysis (**Table 3**) and the soil map. The K is estimated through the following experimental equation.

Table 1. Annual and monthly precipitations data.

Station	J	F	M	A	M	J	J	A	S	O	N	D	P
AînKheil	43	63	61	44	14	3	0	1	12	31	46	48	367
Ahmed Ben Ali	52	46	31	33	6	1	0	1	3	24	34	50	281
Al Gara	59	53	51	38	17	3	1	0	6	33	53	71	383
Barrage O. Maleh	55	46	42	38	18	4	2	2	6	26	48	73	359
Ben Ahmed	62	47	50	39	17	3	1	2	7	31	54	66	376
Bouznika	55	47	55	31	21	6	1	0	6	31	67	77	397
Berrchid	62	50	49	34	16	3	1	1	8	31	57	67	376
Bir Baiz	32	28	23	32	14	8	0	6	7	21	33	48	375
El khatouate	50	60	42	45	21	6	13	2	7	29	30	36	340
Mohammedia	61	53	54	46	20	6	0	1	7	34	71	77	431
Oued Zem	50	42	43	37	18	7	4	2	7	26	48	48	375
Settat	58	54	45	34	14	2	0	1	5	36	53	69	400

Source: Hydraulic Basin Agency of Bouregreg and Chaouia.

$$100K = 2.1M^{1.14} \cdot 10^{-4}(12 - OM) + 3.25(S - 2) + 2.5(P - 3) \quad (4)$$

where: K is the soil erodibility factor ($t \cdot ha \cdot MJ^{-1} \cdot mm^{-1}$), M: (% silt + %fine sand) × (100 − %clay), OM is the % of organic matter, S is the soil structure code, P is the permeability code.

The k index was calculated for each soil type by integrating soil analysis values in the study area and generalized through the soil map.

2.3.3. Topographic Factor (LS)

The (LS) factor reflects the combined effect of slope length and slope steepness on erosion. The empirical equation developed by Wischmeier & Smith is done by following formula.

$$LS = \left(\frac{L}{22.13}\right)^m \times \left(0.065 + 0.045 \cdot S + 0.0065 \cdot S^2\right) \quad (5)$$

where: L is the slope length in meters, S is the angle of slope in percent, m is a constant dependent on the value of the slope gradient: 0.5 if the slope angle is greater than 5%, 0.4 on slopes of 3% to 5%, 0.3 on slopes of 1 to 3%, and 0.2 on slopes less than 1%.

To implement LS factor in Arc GIS, the below formula of Bizwuerk *et al.* (2008) was used [26].

$$LS = \left(FA \times \frac{CS}{22.13}\right)^m \times \left(0.065 + 0.045 \cdot S + 0.0065 \cdot S^2\right) \quad (6)$$

where FA is the flow-accumulation and CS is the cell size.

The flow-accumulation was derived from a MNE ASTER, using Arc-hydrology in spatial analyst extension, according the following algorithm (**Figure 3**).

2.3.4. Cover Management Factor (C)

Vegetation plays an important role in protecting soil against erosion. The vegetation canopy intercepts the rainfall, increases the infiltration and reduces the rainfall kinetic energy.

The C factor is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). Currently, due to the variety of land cover patterns with spatial and temporal variations, satellite remote sensing data sets were used for the assessment of C factor [27]. The C factor has a close linkage to land use types [28]. Ground cover were collected in sample plots with a GPS and reported in Landsat image ETM, the land use at non-sampled location were determined through a supervised classification technique [29].

The major land use types of OM watershed are: agiculture (33.3%), pasture (32.5%), and forest ecosystems (16.5%). The values assigned to each land use are recorded in **Table 2**; it is ranging between 0.05 for dense Forest and 1 for badlands.

2.3.5. Support Practices Factor (P)

The P factor explains human intervention in creating erosion control practices that conserve soil and reduce surface runoff [30]. These practices include contouring, strip-cropping, terracing, strips, etc. [31].

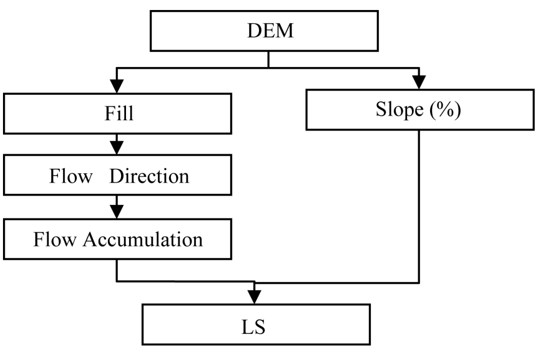

Figure 3. LS factor calculation algorithm.

Table 2. C factor for land use.

Land Use	C Index
Dense Forest	0.05
Open Forest	0.10
Plantation	0.13
Matorral	0.20
Pasture	0.30
Agriculture	0.60
Bad Lands	1.00

Table 3. Physic properties of soil types.

Soil type	Silt (%)	Clay (%)	Fine Sand (%)	Organic Matter (%)	Structure code	Permeability (%)
Calcimanesic Soils	15.1	19.46	41.86	2.81	3	22.34
Isohumic Soils	14.03	37.38	15.00	3.28	2	25.33
Poorly Evolved Soils	18.68	25.84	18.68	1.47	1	13.81
Vertisoils	19.29	53.29	18.07	2.17	4	18.28
Fersialitic Soils	7.98	16.95	56.25	1.47	2	13.82
Hydromorphic Soils	13.03	11.85	41.12	1.53	2	14.18
Raw Mineral Soils	18.68	25.84	27.47	1.47	2	13.82
Brown Soils	16.54	15.44	20.85	2.70	3	21.65
Brown Soils	16.54	15.44	20.85	2.70	3	21.65

Source: National Institute for Agricultural Research of Settat.

The values of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices; the minimum values correspond to built-up-land and plantation area with strip and contour cropping. The lower the P value, the more effective the conservation practices. For Oued El Maleh watershed, except two perimeters namely Seffoud and Bouhrar, were we found brenched plantation, there is no significant support practice.

3. Results

3.1. Evaluation of R, K, LS, C, and P factors

The R values were based on the formula modified by Arnoldus using annual and monthly precipitations, the data were provided from 12 stations for 30 years. R values oscillate between 62.59 to 104.63 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ with an average of 79.06 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$ (**Figure 4**). We observe a weak spatial variation of R which increases following the South-East to North-West direction.

At the watershed level, the erodibility index K is between 0.07 and 0.39 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ (**Figure 5**). The vertisoils, isohumic soils and brown soils are little erodible whereas raw mineral soils, poorly evolved soils and calcimanesic soils, which are mainly encountered in the basin are moderately erodible.

On the other Hand, fersialitic soils and hydromorphic soils have high erodibility values, reflecting their high susceptibility to erosion.

Figure 6 shows that the majority of the study area has LS Values less than 1.5. Some specific areas with a big steep slope, such as along the river have LS values greater than 4.5.

The values assigned to land cover range between 0.05 for dense forest and 1 for badlands. 0.6 was attributed to agriculture which is the dominant land use (**Figure 7**).

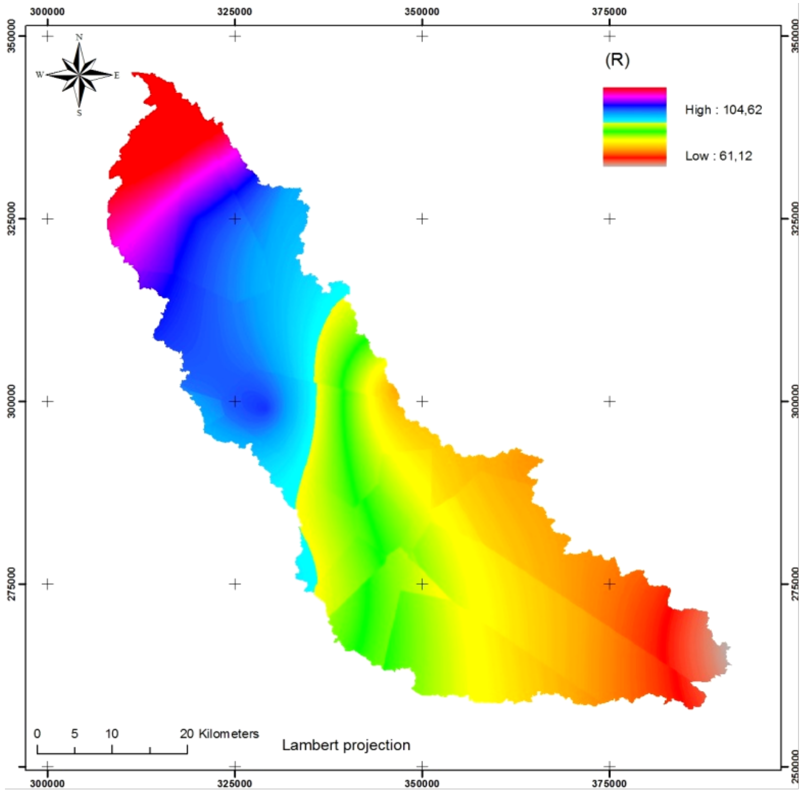

Figure 4. Erosivity factor (R).

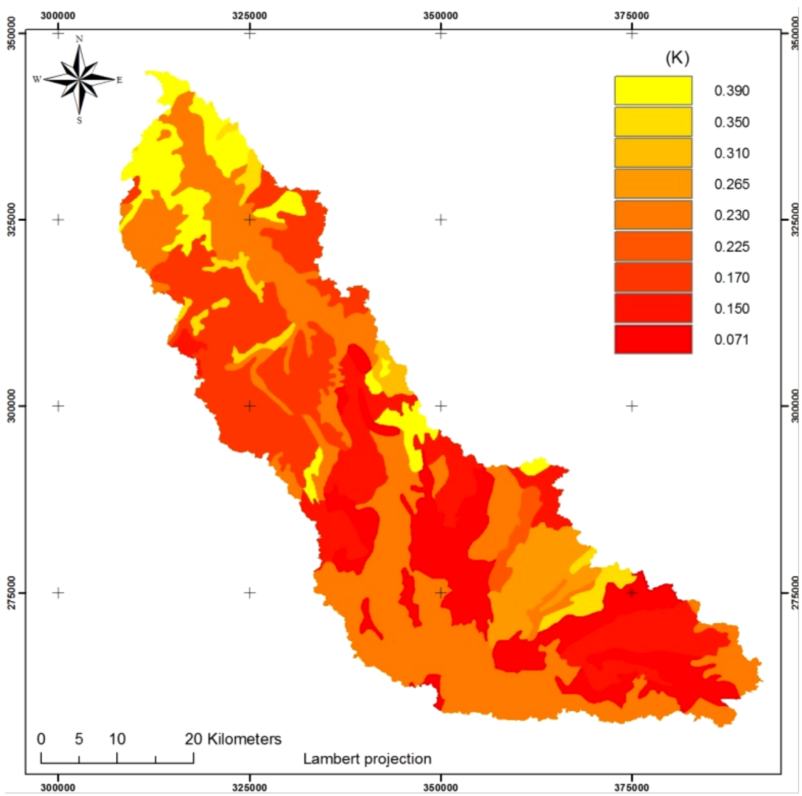

Figure 5. Erodibility factor (R).

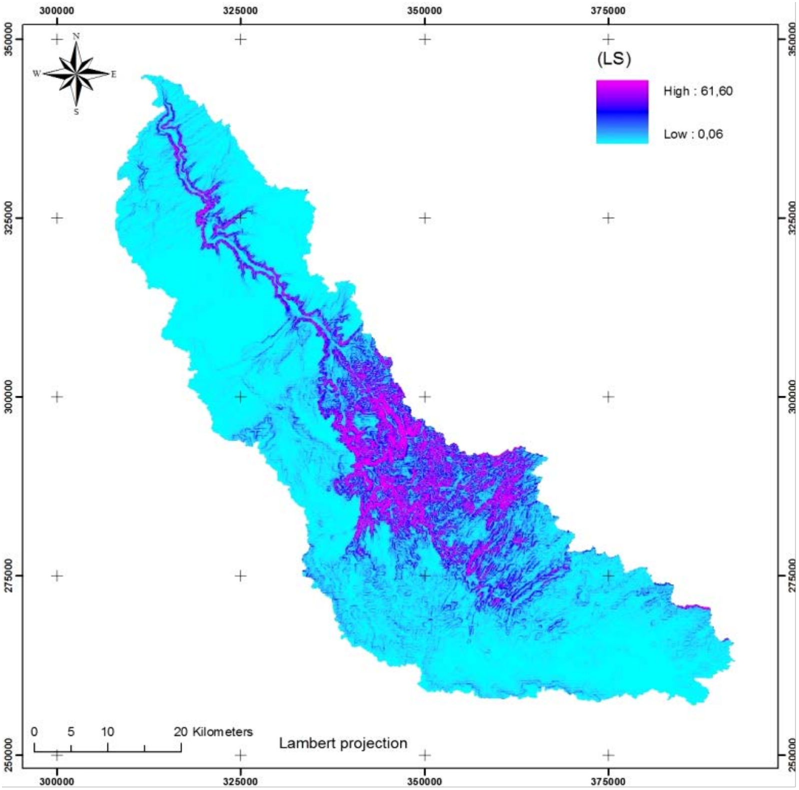

Figure 6. Topography factor (LS).

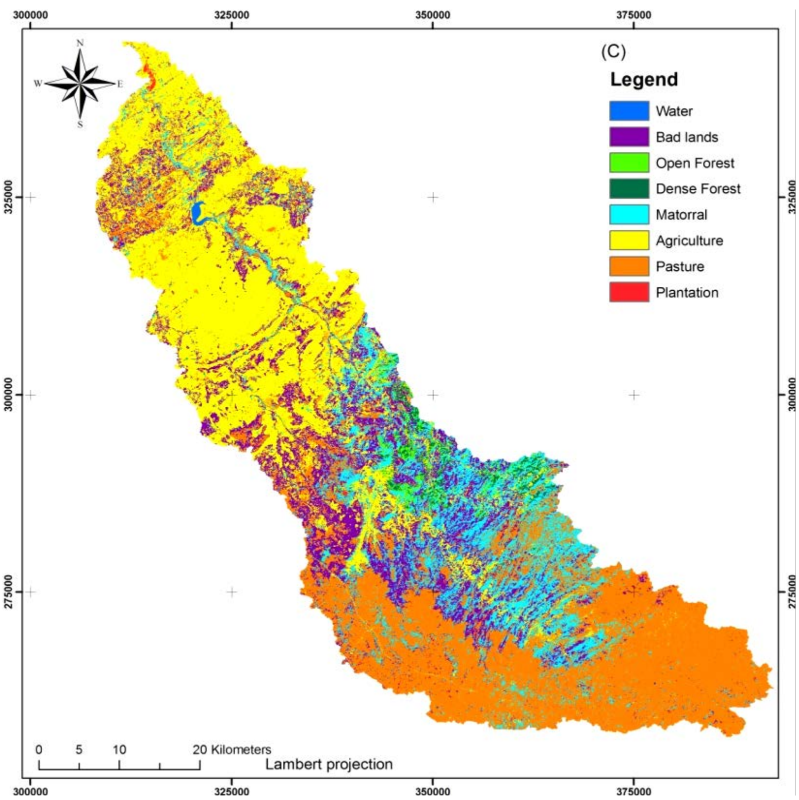

Figure 7. Land cover factor.

For both Seffoud and Bouhrar perimeters, we assigned the P factor value of 0.5 and of 1 for all other areas of the watershed.

3.2. Evaluation Soil Loss

The empirical USLE model was implemented in ArcGIS [32] using map algebra on raster layers on different indices involved in the model. All the factors were overlaid to generate the soil loss map (**Figure 8**). The maximum and minimum losses are respectively about 0.02 $t \cdot ha^{-1} \cdot yr^{-1}$ and 501.40 $t \cdot ha^{-1} \cdot yr^{-1}$. The average value per hectare is 8.21 $t \cdot ha^{-1} \cdot yr^{-1}$.

Sadiki and al (2009) reported a soil classification system according to their susceptibility to erosion [33]. Indeed, soils can tolerate a significant agricultural production with soil loss not exceeding 7 $t \cdot ha^{-1} \cdot yr^{-1}$. Beyond 7 $t \cdot ha^{-1} \cdot yr^{-1}$, soil losses are important and can compromise agricultural production. Between 20 and 30 $t \cdot ha^{-1} \cdot yr^{-1}$, erosion is considered high and is considered too high from the threshold 35 $t \cdot ha^{-1} \cdot yr^{-1}$.

The analysis of **Table 4** shows that 73% of the area is exposed to law erosion, which explains why agriculture is the dominant practice in the study area.

Sub-catchment and soil loss maps were integrated to compute erosion for different sub-catchment (**Figure 9**). According to the calculated Values, Laatach sub-catchment records the highest average of soil loss (**Table 5**). However, it's Zamra sub-catchment which more contributes to sediment production. This could be explained by its big area.

4. Conclusions

The watershed of Oued El Maleh suffered severe climatic aggressiveness with an average of 79.07 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$. The weighted average value of k for the watershed is 0.21 with a median of 0.23, confirming the susceptibility of soils to erosion in this watershed.

The average LS value is 1.26. According to the grading standards of Manrique (1988) related to LS factor, we can say that most of the land in the watershed belongs to the low risk class (0 - 2 units). The highest value of LS coincides with rough areas.

Table 4. Classification of soil loss in watershed Oued El Maleh.

Soil Loss (t/ha/Yr)	Intensity	Area (Km^2)	Area %
0 - 7	Weak	1891.00	73.38
7 - 20	Moderate	440.67	17.10
20 - 30	Strong	87.36	3.39
30 - 35	Very Strong	26.80	1.04
>35	Extremely Strong	130.65	5.07
Total		2576.48	100

Table 5. Prioritization of sub-catchment based on soil loss assessment.

Sub Catchment	Min (t/ha/yr)	Max (t/ha/yr)	Mean (t/ha/yr)	Sum (t/yr)	Priority N°
Zamra	0.02	464.22	8.60	1060287.35	1
Laatach	0.04	501.39	18.44	557208.25	2
Oued El Maleh Dam's Upstream	0.05	442.12	8.35	191112.64	3
Oued El Maleh Dam's Downstream	0.07	417.83	8.23	155600.64	4
Zahiwine	0.02	121.02	3.46	99758.39	5
Hassar	0.05	114.63	2.21	74757.30	6
Total	0.02	501.39	8.21	2138724.56	

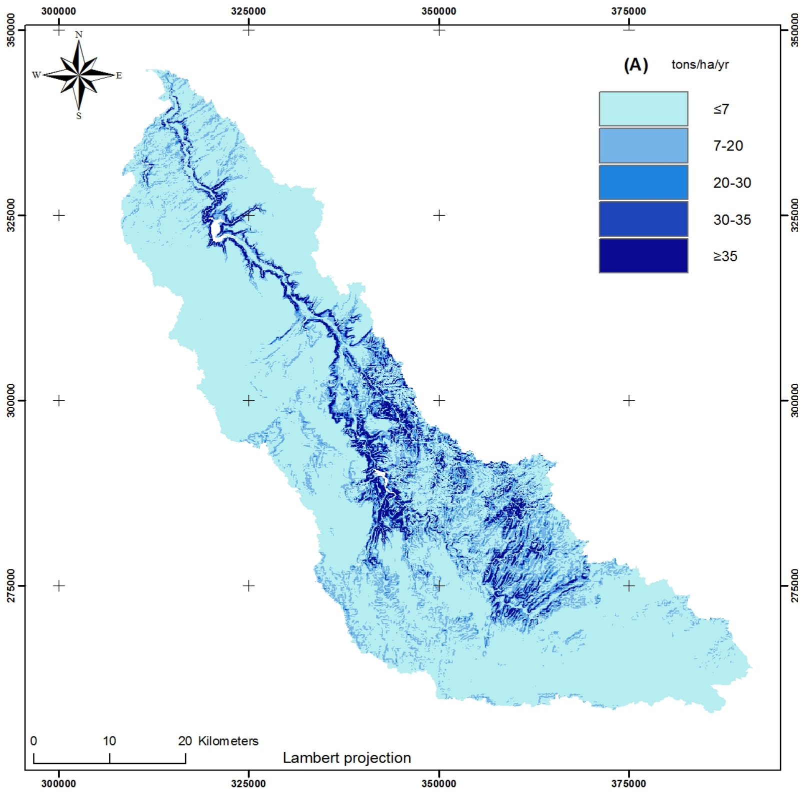

Figure 8. Annual soil loss in watershed Oued El Maleh.

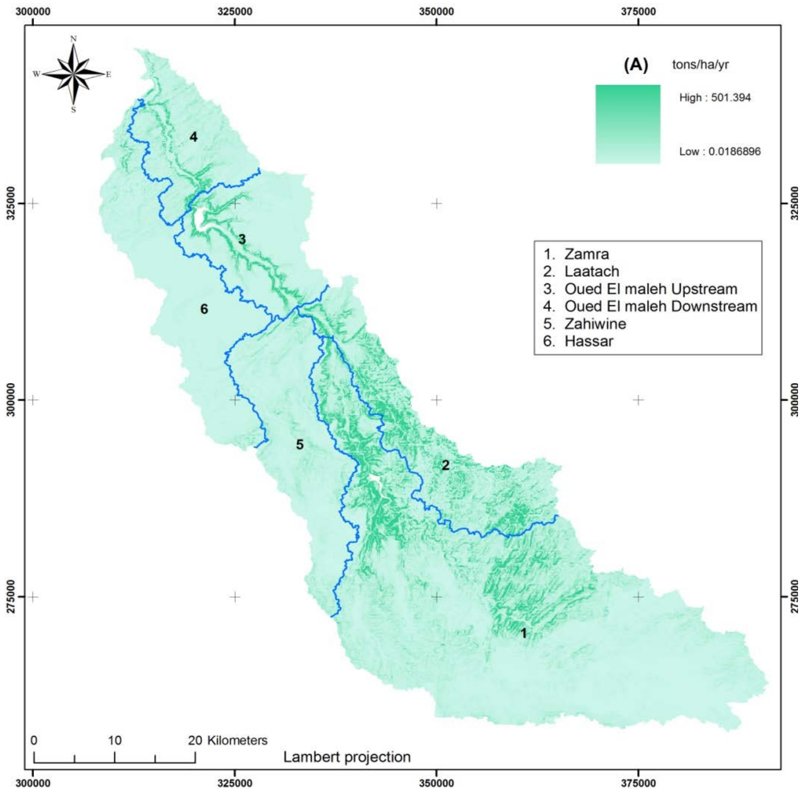

Figure 9. Annual soil loss in Oued El Maleh sub-catchments.

The role of vegetation is crucial. The average C value in the watershed is 0.5. This reflects the modes of space use characterized by both a dominance of agriculture that less protects the soil as well as the scarcity of the forest domain which well protects the soil both by its root system and its canopy.

The rate of erosion is generally considered moderate in most of the watershed with spatial variability. Moreover, it appears from the analysis of the potential erosion map that the majority of produced sediment comes from Zamra and Laatach sub-catchment whilst the minimum sediment produced is generated in Hassar sub-catchment.

In general, USLE is used to estimate average annual soil loss, the use of remote sensing and GIS allows us to spatialize the potential risk of erosion however; the uncertainties regarding data may introduce uncertainties about soil loss estimates.

Although the USLE has been criticized for its lack of applications in areas different from its development as well as for giving erroneous results, it is still regarded as best generally available model that has been virtually tested in all environments of the world. Bouqdaoui (2007) has synthesized them [34]. Sadiki and al (2009) concluded that the model underestimates the real soil loss which seems normal due the fact that the model doesn't take into account other forms of erosion.

On the whole, this work has approached the problem of erosion in the watershed of Oued El Maleh, which has experienced several floods. At its end, the use of GIS and remote sensing has facilitated the identification of the erosive potential of the watershed and identify sub-basins that contribute most in the production of sediment. This is a support decision making and may help guide managers for selecting priorities to be addressed in anti-erosion management areas with the purpose to preserve human lives and infrastructure.

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