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CARTOGRAPHY OF THE VULNERABILITY TO EROSION BY THE COMBINATION OF SATELLITE IMAGES AND GIS OF OUERGHA WATERSHED (MOROCCO)

I. Jaouda, A. Akhssas, L. Ouadif and L. Bahi
3GIE Laboratory, Mohammadia Engineering School, Mohammed V University in Rabat, Morocco
E-Mail: Jaouda.imane@gmail.com

ABSTRACT

This paper presents the results of the study concerning the mapping of the spatio-temporal evolution of the land cover based on the remote sensing data (satellite images) over a period starting from 2004 to 2014 on one hand, and the erosion process modeling on the other hand using the Universal Soil Loss Equation. The Ouergha watershed with an area of 6190 Km2 and elongated in an east/west direction, is characterized by a slope oscillating between 0 and 72 °. Erosivity Factor R varies between 66, 7 and 130, soil erodibility factor varies between 0.2 and 0.55, topographic factor LS varies between 0 and more than 100. The superposition of the different maps obtained by analyzing these parameters, has made it possible to deduce the global erosion map from which it appears that the phenomenon of erosion affects the entire Ouergha watershed but to different degrees, With 45% of the watershed's area subject to an erosion between 50 and 300 t/ha /year recorded in the entire watershed's area. The highest value of more than 200 t/ha/year is observed in the eastern half of the basin.

Keywords: erosion, erodibility, climate change, land cover, Ouergha, Morocco.

1. INTRODUCTION

Soil represents the support for crop and agriculture which are the foundations for a social and economic development of civilizations. However, this development often leads to an excessive use, the waste of soil resource and their degradation. The latter, being a dynamic process widespread worldwide, appears under the combined influence of particular climatic conditions and poor soil management (Coote *et al.*, 1982; Taibi *et al.,* 1990; Wicherek and Laverdière, 1993).

To address these environmental issues, affecting researchers and engineers as well as territorial managers, erosion risk map is often produced in order to serve as a support for the understanding of the phenomenon. The importance of the damage associated with the erosion process has made it essential to map its hazards and / or risks in order to identify the priority areas and to improve the coherence of prevention and protection measures.

The main objective of the study carried out in this paper is the mapping of water erosion hazard at the Ouergha watershed in the north of Morocco, using the empirical USLE model (Universel Soil Loss Equation, Wischmeïer and Smith (1978)).

Modelling was carried out by mapping the various factors under a Geographic Information Systems (GIS) platform, and their superposition to develop a quantitative map of the water erosion hazard in t/ha /yr. The result is a spatially referenced cartographic document that provides a decision-making tool in terms of risk management and protection of natural resources.

The watershed of the El WAHDA dam is drained by OuedOuergha. It covers an area of 6190 km^2. It is located in the North of Morocco between latitudes 34 ° 25 '- 35 ° 25', and longitudes -5 ° 24 '- -3 ° 45', and extends over the major part of the Rif mountain. It is bounded in the north by the Rifi peak passing through Ketama, Bab Berred and Bab Taza, distant from the Mediterranean of about 30 km, in the South, by the watersheds of Sebou, and in the east by the rivers Moulouya and Sebou (Figure-1).

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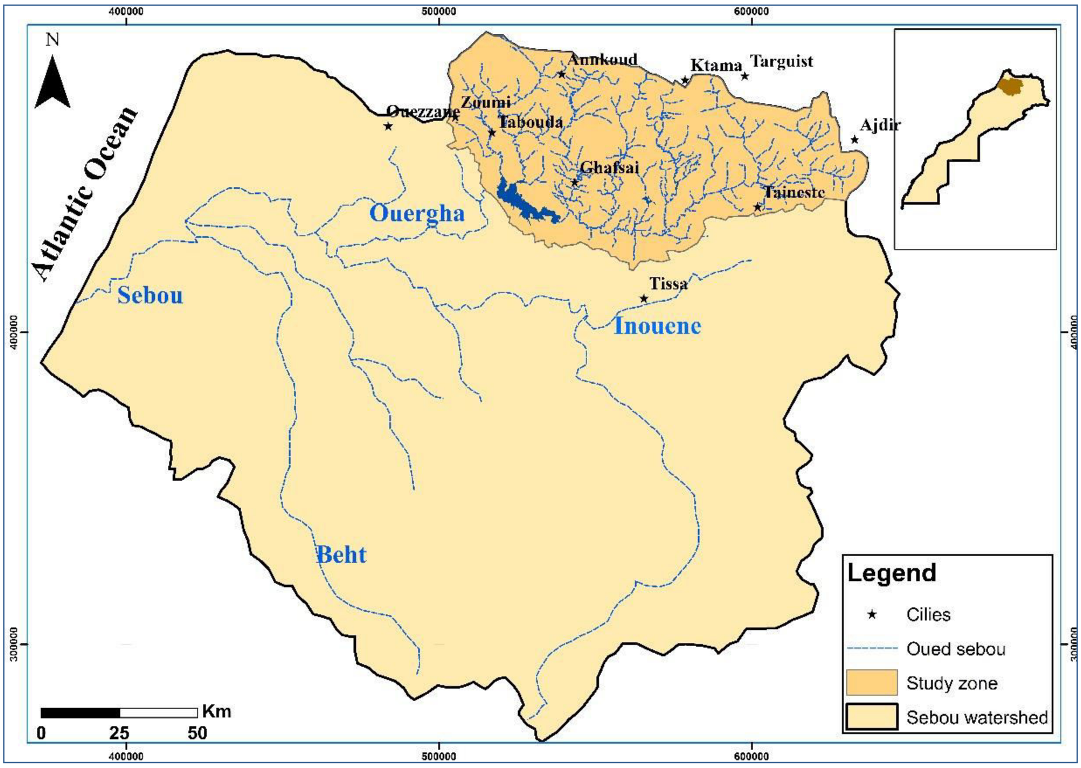

Figure-1. Geographical location of the Ouergha watershed.

Geologically, the watershed of OuedOuergha is shaped in a part of each of the two structural assemblages (the Intra-Rif, the Meso-Rif) separated by the Tahar Souk basin which is a basin for post folds tortoises deposits (Figure-2). Post-fold deposits are indigenous miocene formations deposited during the Tortonian transgression. They consist of conglomerate coarse sediments at the base and become finer upwards giving sandstones, ending in a thick series of clayey marls. The northern part of the watershed is the intra-Rifi zone, formed by two thrust sheets; the units of Ketama and Tangier. They take the form of mobile, para-indigenous formations made up of elements ranging from the Triassic to the lower Tortonian. The Ketama unit has a sandstone flysch of Lower Cretaceous with a thickness of a few Kilometres (Asebryi *et al.*, 1991; 1992; 1993). The unit of Tangier is considered as the more or less detached cover of the Ketama unit, it is formed by shales and limestones of the Middle and Upper Cretaceous (Asebryi *et al*.; 2003;2006; 2007; 2014). The Meso-Rifi zone appears in the south of the watershed in form of a window beneath the intra-Rifi folds (Chalouan A. *et al*., 2014). The grounds of this unit are constituted in the study area by a Jurassic-Cretaceous series, in the region of Taounate constituted of the marls surmounted by a molassic formation composed of sandstones and conglomerates (Leblanc, 1979).

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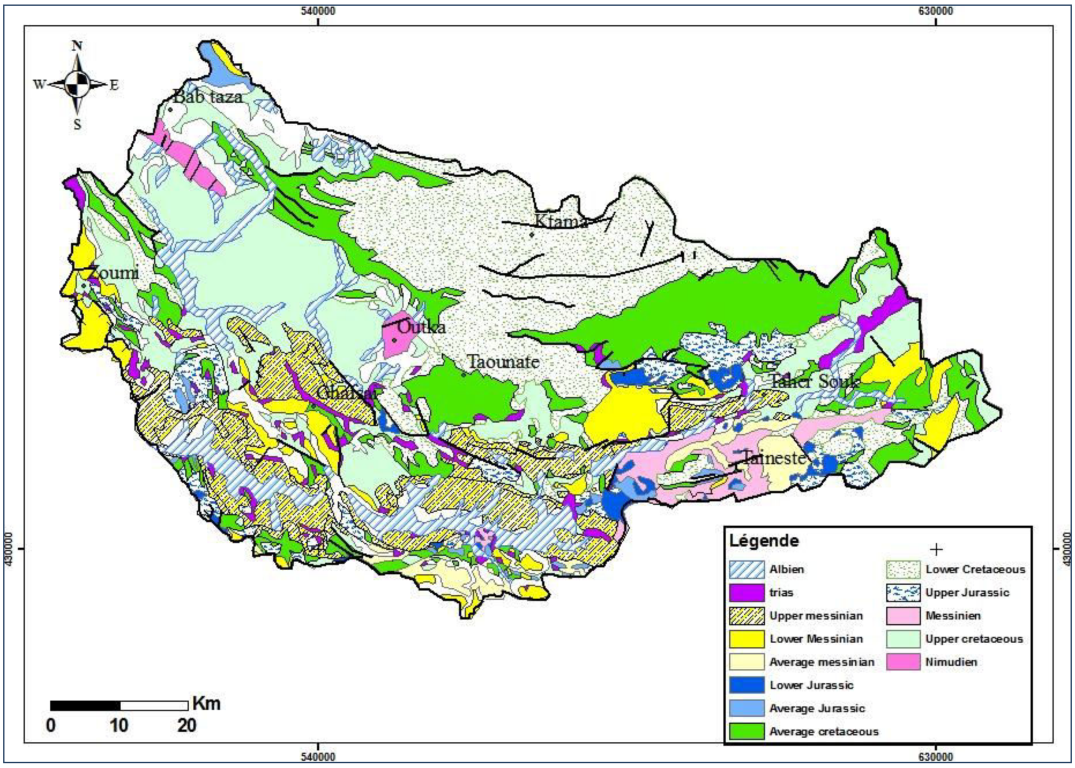

Figure-2. Geology of the Ouergha watershed.

The Ouergha watershed has a mountainous character with altitudes ranging between 83 m and 2450 m. It shows a variety of reliefs, with structural forms, closed depression, ravines and accumulation forms represented by alluvial terraces (Figure-3).

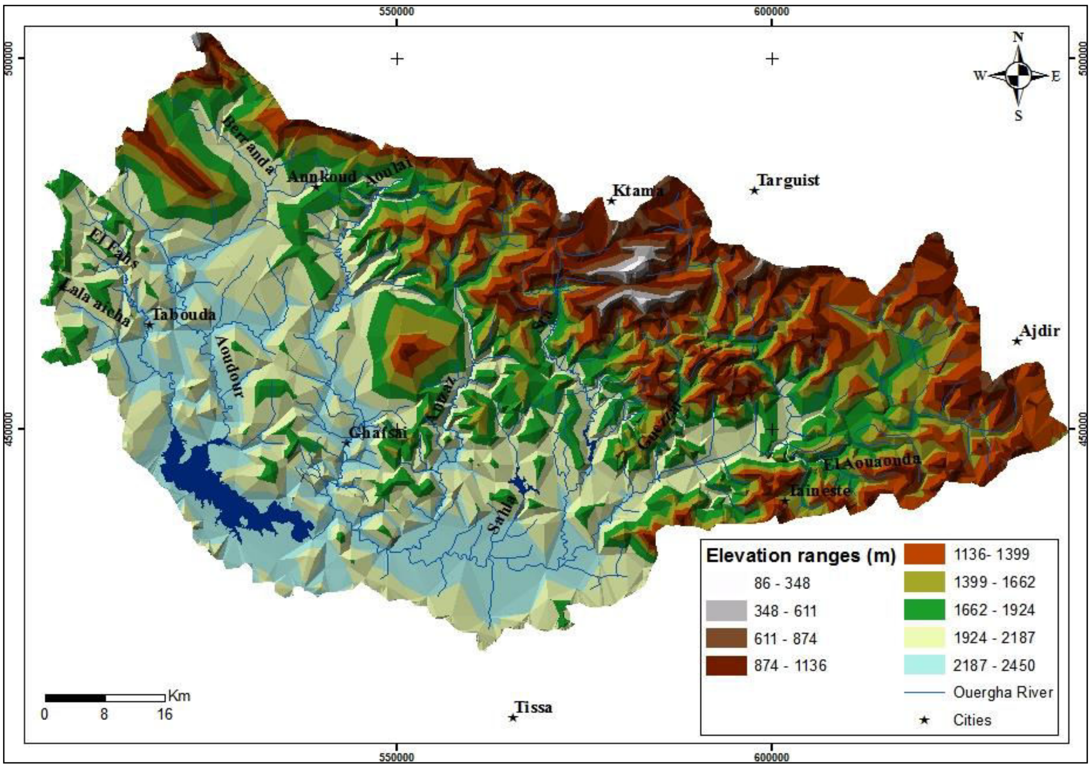

Figure-3. Elevation classes of the Ouergha watershed.

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According to the elevation class map, reliefs are considered a major factor reflecting the ability of a watershed area to runoff (Figures 4; 5).

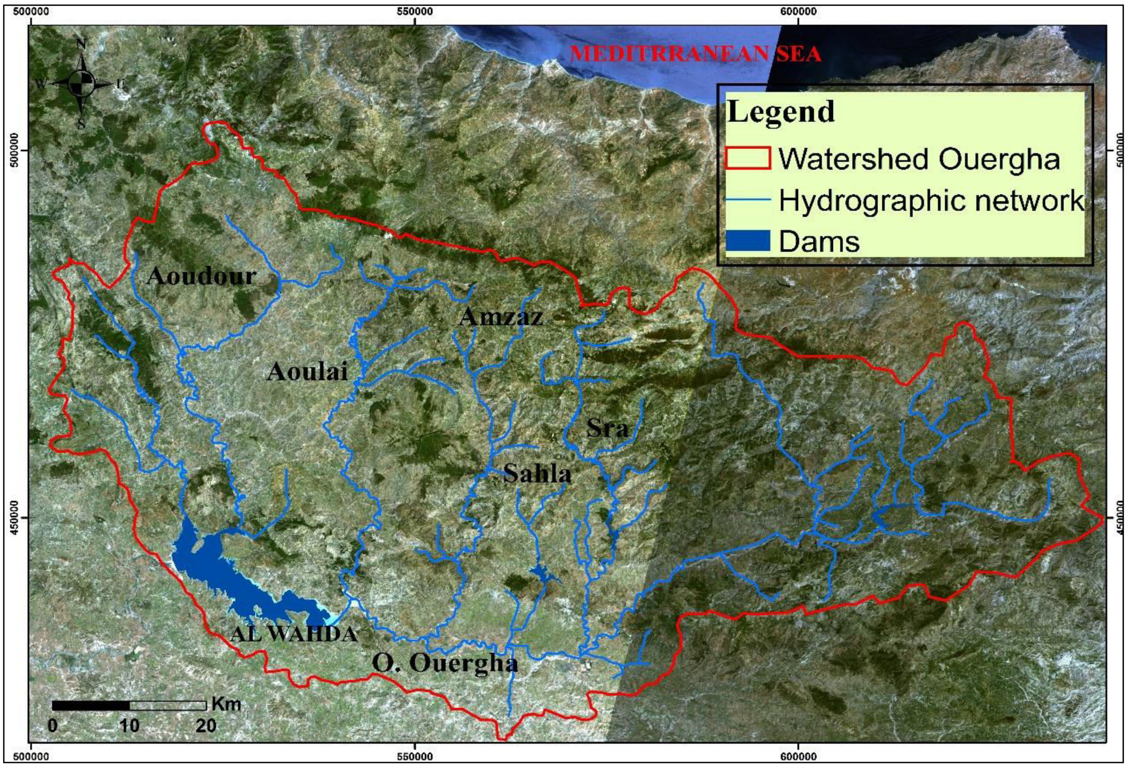

Figure-4. The OuedOuergha locality and its main tributaries.

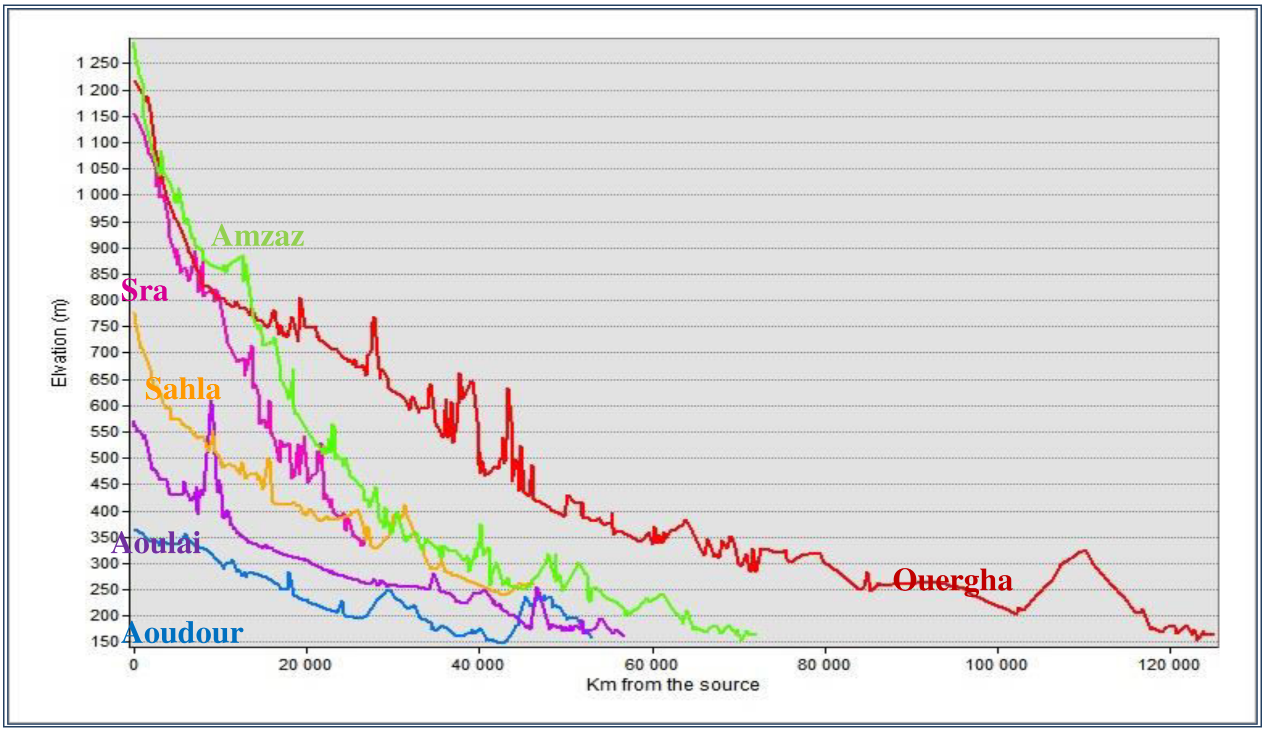

Figure-5. Profiles of the Ouergha river system from headwaters to Atlantic Ocean. The color bar indicates the area of the upstream drainage area.

The average elevation of the watershed uphill of the M'Jara is 850m. The lowest point is the low water flow of Ouergha in M'Jara is 92 m, and the peaks exceed 2000m. The high average elevation of this watershed is

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one of the reasons why this watershed is one of the best watering in Morocco. The basin can be divided into 3 distinct topographical areas: high mountains (elevation > 1200 m), mountains of average elevation (400 m < elevation <1200 m) and plains of the valley (elevation <400 m).

3. METHODOLOGY

Our approach is based on the use of remote sensing data for a specialized knowledge of the differentiation factors of erosion (land cover, importance of plant cover ...) and on the use of geographic information system (GIS) for analysis and modelling of the erosion processes. For a multi-date monitoring of erosion at the watershed scale, four satellite images were used: A Spot HRV image taken on May 10, 2004 and two Landsat images taken on May 20, 2004, May 20, 2014.

Water erosion results from the interaction of many factors: the climate (rain, temperature ...), the soil properties (organic matter, structural stability, infiltration capacity, etc.), the relief (length and gradient of the slope), and cultivation practices (tillage) and plant cover. According to Nearing (2000), the spatial and temporal modification of this interaction can induce an amplification of water erosion.

After mapping the land-cover for each shooting date, soil losses were estimated by the RUSLE module integrated into GIS.

The empirical RUSLE model combines the factors that affect the extent of erosion and is as follows:

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

Where:

- A: Land loss rate in tonnes per hectare per year (t/ha/yr);
- R: Rainfall erosivity in Mega joules millimetre per hectare hour (MJ mm /ha h);
- K: Soil erodibility in tonne hour per Mega joules millimetre (t h/MJ mm);
- LS: Slope and tilt length (without unit);
- C: Plant Cover Factor (without unit);
- P: Factor taking into account anti-erosion practices (without unit).

Rainfall erosivity (R) is defined as an ability to cause erosion. It depends mainly on the intensity of rain or the resulting kinetic energy (Stengel and Gelin, 1998). This energy derives from the diameter of raindrops and their fall speed. The effectiveness of rainfall in erosion processes is related to the roles it plays in the detachment of soil particles and especially in the formation of runoff (Marcey and Berville, 2003).

Some authors (Kalman, 1967 and Arnoldus, 1980) have developed alternative formulas that involve only monthly and annual rainfall to determine the R-factor. From the available climatic data (period 1978-2008) for an average annual rainfall of 381 mm, the R index was calculated on the basis of the ARNOLDUS formula:

$$\text{Log R} = 1.74*\log\sum_{i=1}^{12}\left(\frac{pi^2}{P}\right) + 1.29 \quad (2)$$

Where P_i is average monthly precipitation and P average annual precipitation.

Soil Erodibility (K) is a function of organic matter and soil texture, permeability and profile structure (Heusch, 1971). It ranges between 0.70 for the most fragile soils and 0.01 for the most stable soils. We have evaluated the K index for the different types of soils by means of the Wischmeier nomogram using the basin's soil map (Figure-6), soil infiltrability data obtained by the rain simulation method (Tribak And al.2006). Factor K values lying between 0.1 and 0.6 shows net soil fragility and its susceptibility to erosion (Table-1).

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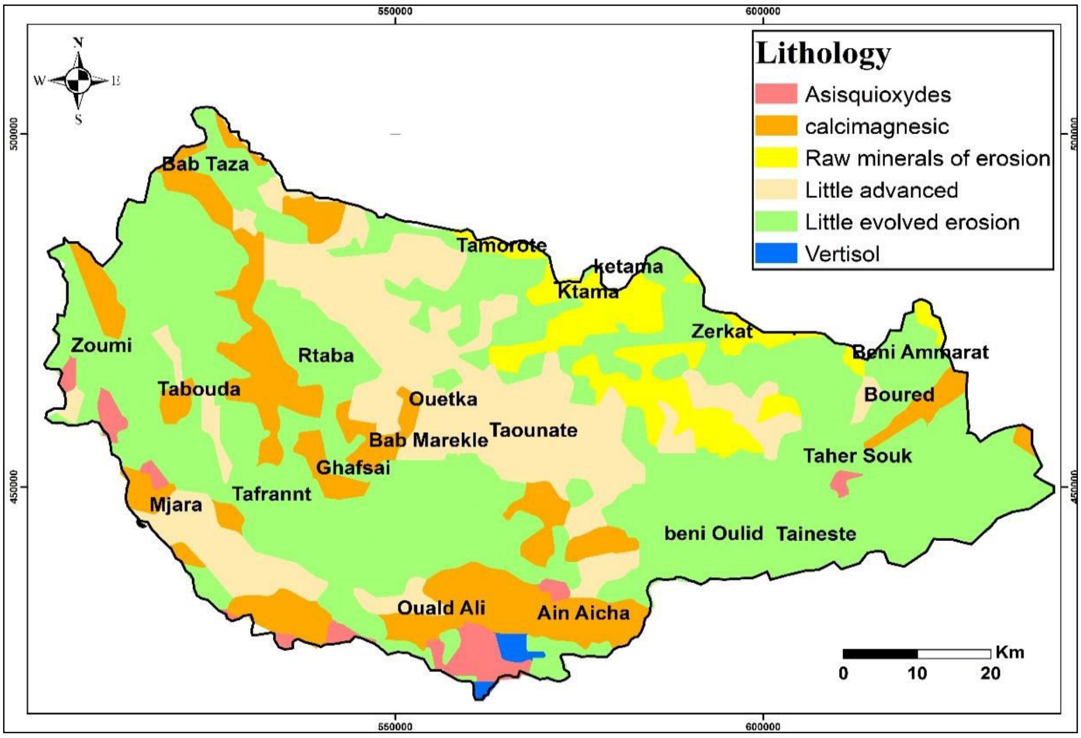


Figure-6. Map of the lithology of the Ouergha watershed.

Table-1. The K factor values by soil type.

Soil type	K metric t/ha
Little evolved lithic soil	0.32
Little evolved soil Of alluvial input	0.39
vertisol	0.36
Brown calcimagnic soil limestone modal	0.23
Brown calcimagnic soil limestone vertic	0.22
Fersiallitic soil	0.46

Topographic factor (LS) is fundamental to explain the extent of erosive phenomena. The gradient, slope shape and length of the largest slope have an important role. Batti and Depraetere (2007) admit that the average erosion per unit area increases with the length of the slope and explain this by the fact that the longest slopes allow a greater accumulation of runoff, which increases the overall energy of the latter and its possibilities of detachment and transport. On the other hand, according to a FAO analysis (1994), the erosion phenomenon is also visible on gentle slopes. The calculation of the LS factor of the OuedOuergha watershed is carried out by means of the ARC-GIS. The latter uses the DTM (Digital Terrain Modulus) with a resolution of 20 m to calculate the degree of the slope, the orientation and the cumulative length of the slope and finally calculate the LS factor.

Plant Cover Factor (C), plant cover is, after topography, the second most important element to control the risk of soil erosion (Roose, 1996). In the RUSLE model, the effect of plant cover is incorporated into the cover installations factor. It is defined as a ratio of soil loss on crops under specific conditions with respect to the corresponding loss in soil on fallow lands (Wischmeier and Smith, 1978).

The effectiveness of plant cover and residuals in reducing erosion depends on the type, extent and density of the plant cover. The combined vegetation and residues, covering the soil completely, intercept the rain and are the most effective way to reduce loss in soil. Partially incorporated residues and their roots are also important because they facilitate infiltration (Arnold *et al.*, 1989). The value of C depends mainly on the percentage of the plant cover and the growth stage. The map of the C factor for the OuedOuergha watershed was deduced from the land use maps. These were determined from the exploitation of remote sensing data. Values for different land use patterns range between 0.08 and 0.75 (Table-2) (Kalman, 1967).

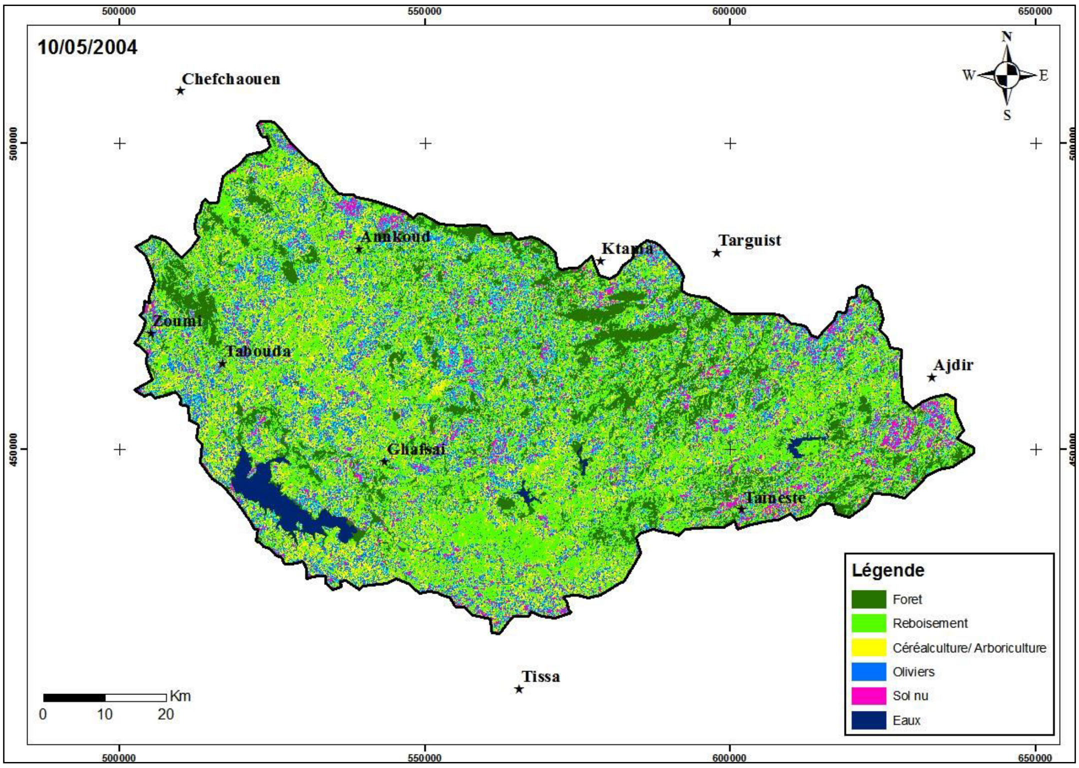
Table-2. Factor C values by land-use type.

Types of soil cover	C Factor
Bare land	0.75
Crops / Arboricultures	0.25
Olive trees	0.28
Reforestation	0.15
Forest	0.08

Factor expressing soil protection by agricultural practices (P), this factor takes account of purely anti-erosive practices, such as tillage in contour line or mounding, or ridging in contour line. It varies between 1 on bare soil without any anti-erosion installations to about 0.1 when on a low slope; we practice partitioned ridging (Roose 1996). Given the condition of the anti-erosion installations in the region, the value 1 is assigned to the factor P.

4. RESULTS AND DISCUSSIONS

The analysis of satellite data identified six main types of land cover (heavily degraded land "bare soil", grains crops, a mix of grains crops and arboriculture, olive trees, reforestation and forest) in the watershed of OuedOuergha. Figure-7 shows the evolution of land cover in the study area in 2004 and in 2014.



(a)

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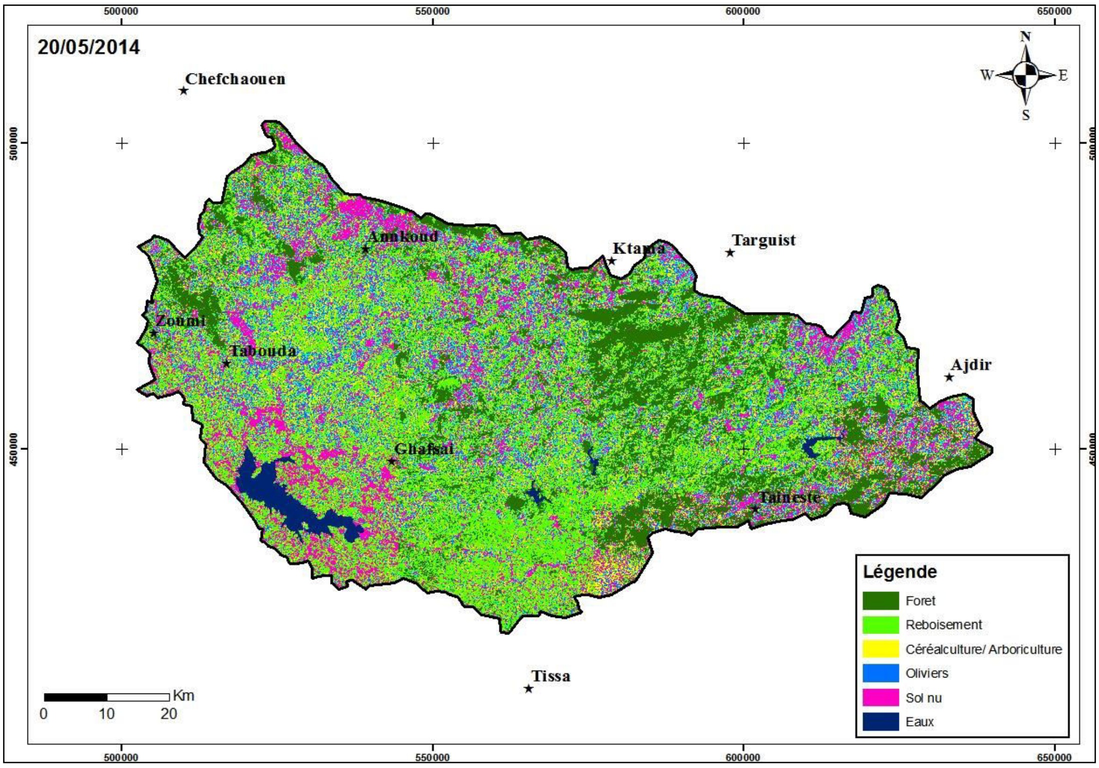

(b)

Figure-7. (a) Soil cover in 2004; (b) Soil cover in 2014.

The diachronic study of land cover reveals a change in the natural area with an increase in groves of olive trees (+ 45%), an extension of heavily eroded soils (raw land) (+ 59%) and a reduction in the areas of grains crops to the benefit of crops in presence of arboriculture. This increase in groves of olive trees is justified by the olive planting operation promoted by the State during the 1990s (Taza DPA, 1997 and 2007). The areas occupied by the forest and the reforestation have undergone a change and have seen their areas reduced.

After the land-cover mapping for each shooting date, soil losses (Figure-8A) were estimated by the superposition of many factors which are:

- The map of erosivity R (Figure-8a),
- The map of the soil erodibility K (Figure-8b),
- The map of the slope length LS (Figure-8c)
- The map of the plant covers C (Figure-8d).

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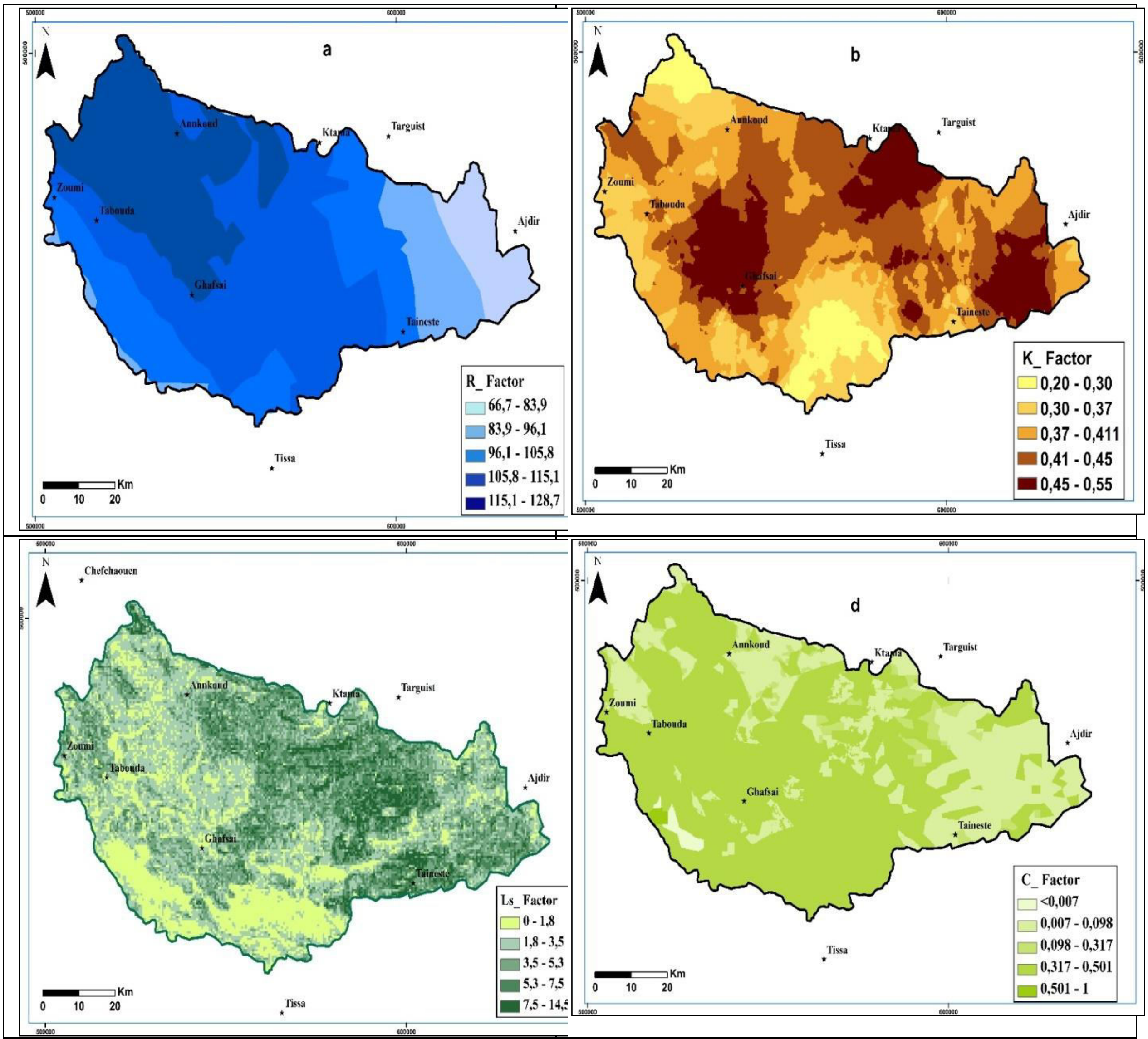

Figure-8a. Map of the erosivity; 8b: map of erodibility; 8c: map of the slopes length; 8d: plant cover map.

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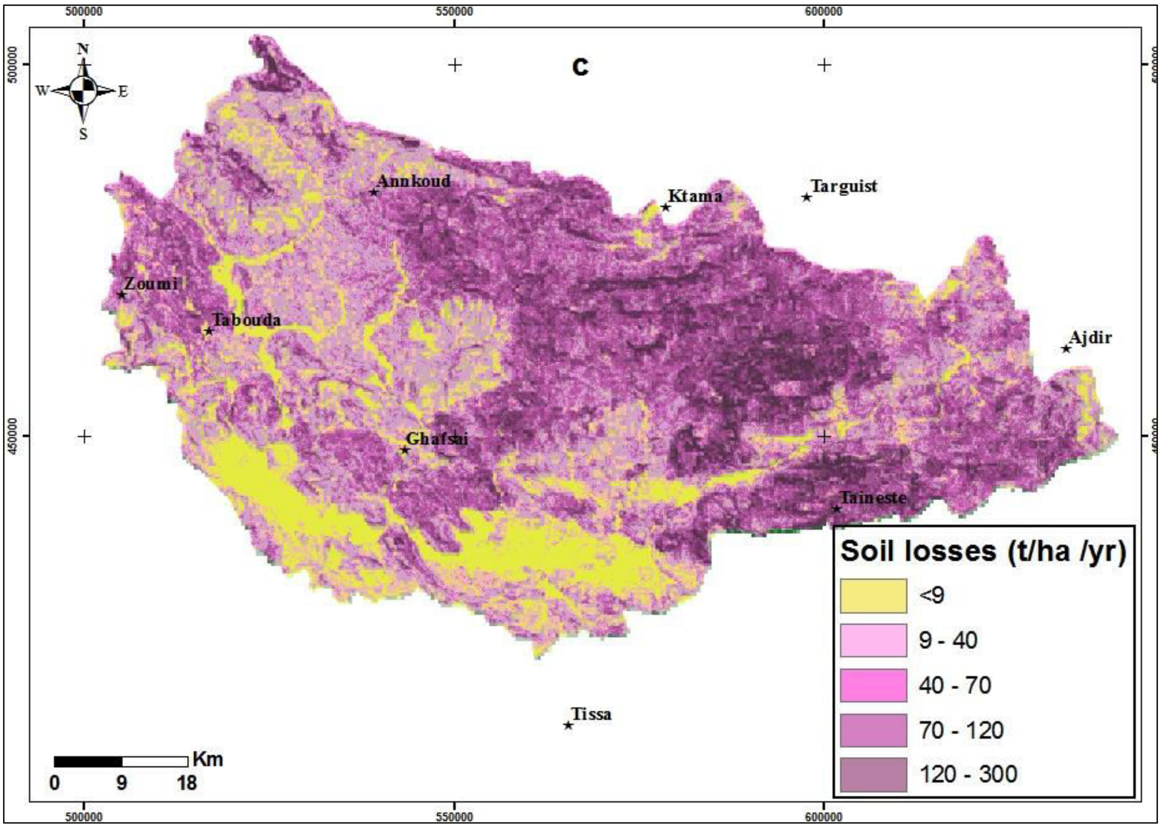

Figure-8A. Maps of soil loss in OuedOuergha watershed.

The highest values which exceed 200 t/ha /yr are recorded in the eastern half of the basin, while the average values between 50 and 100 t/ha /yr are distributed over the entire basin. This is mainly explained by the dominance of little evolved soils while exhibiting a high erodibility reaching 0.5 and contributing in accentuating the soil losses. In the western side of the basin, the dominance of vertisols, with low erodibility (0.2), contributes in reducing the soil losses. The low plant cover downstream the watershed with a factor C of 0.5 to 1, promotes marly landslides, gully erosion of shale, and the incisions of tender soils (Figure-9). The steep slope upstream the watershed leads to significant losses, despite the presence of a vegetation cover. These results can be explained by the fact that, despite the presence of vegetation, the proportion of soil surfaces on steep slopes (> 30%) leads to significant losses.

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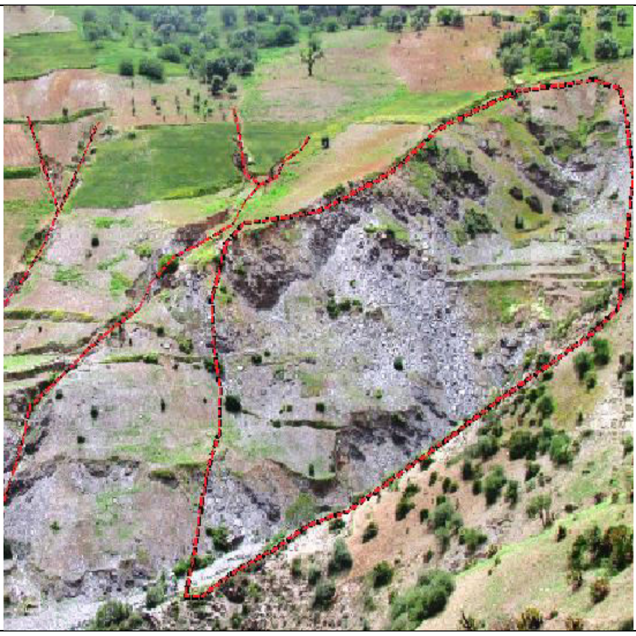
a: Incisions by waters in marly lands

b: landslide in soft soils and erosion of marl by wild waters



c: Ravins deep enough in shale in the center of the Ouergha watershed

d: Meandre of the Oued Aoulai; Note the abrupt concave shore and erosion in marls

Figure-9. Erosion by water in OuedOuergha watershed.

5. CONCLUSIONS

The quantification of soil losses at Ouergha watershed was carried out according to Universal Soil Loss Equation (USLE) integrated into a Geographic Information System. The soils of the Ouergha watershed, consisting mainly of marly tender soils, are influenced by several factors that favor the erosion phenomenon. The steep slopes, the low plant cover, high rainfall and soil erodibility are factors that play a key role in erosion of the watershed lands. An area of about 80% of the Ouergha watershed is subjected to severe erosion with losses ranging between 20 and 300 t / ha / year, located in the central part of the basin. Low soil loss concern only 20% of the watershed area, and is located in the south and the west of the basin. This degraded soil condition is favoured by erosion factors which also combine to accelerate erosion, steep slopes (62%), advanced degradation of plant cover and highly erodible soils (K> 0.4). Therefore, this watershed, analyzed in detail, should constitute a representative zone for the entire OuedSebou watershed. The most exposed zones to the risk of erosion are determined in order to protect the natural environment, to minimize or even avoid the turbidity of the water and the siltation of the AL WAHDA dam located just downstream the Ouergha watershed.

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