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Assessment of Soil Erosion by RUSLE Model using Remote Sensing and GIS - A case study of Ziz Upper Basin Southeast Morocco

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Abstract

Accelerated by inadequate human activities, water erosion can cause many environmental and socio-economic problems on -and off-site: loss of biodiversity, reduced productivity of agricultural land, siltation of dams, increased risk of flooding. The quantification of soil erosion is essential in the management and conservation of the soil and water resources. Modeling soil erosion can provide a lot of information to estimate soil loss and sediment yields at large-scale. In this study, the Revised Universal Soil Loss Equation (RUSLE) integrated into a GIS was used to quantify soil losses in the large upper watershed of Ziz (4435 km2) in southeastern of Morocco. The RUSLE parameters were estimated based on data from satellite imagery, DEM-SRTM and national watershed management plan studies. The results show that annual average of the potential soil erosion is 489.5 t. ha-1. yr-1 and the specific sediment yield is 36.4 t. ha-1. yr-1. The main sources of sediment are in the watershed upstream parts and some deposition zones are located before the catchment outlet. These soil losses contribute to the annual siltation of the Hassan Eddakhil dam by a rate of 3.5%. The application of principal components analysis to soil erosion factors shows an important influence of the soil erodibility factor (K) followed by the topographic factor (LS) then crop management factor (C). These modeling results will provide data within the Moroccan southeastern High Atlas that can constitute a road map for future soil erosion projects and it can be a useful tool for proposing soil conservation strategies.

Keywords: *water erosion, RUSLE, remote sensing, GIS, Ziz basin, southeast Morocco*

Rezumat. Evaluarea eroziunii solului prin modelul RUSLE folosind metode de teledecție și SIG – Studiu de caz: bazinul superior al râului Ziz din sud-estul Marocului

Accelerată de activitățile umane inadecvate, eroziunea apei poate provoca multe probleme de mediu și socio-economice, atât în perimetrul propriu-zis, cât și în afara acestuia: pierderea biodiversității, productivitatea redusă a terenurilor agricole, colmatarea barajelor, riscul crescut de inundații. Cuantificarea eroziunii solului este esențială în gestionarea și conservarea resurselor de apă și sol. Modelarea eroziunii solului poate oferi o mulțime de informații pentru a estima pierderile de sol și volumul de sedimente pe scară largă. În acest studiu, ecuația revizuită universală a pierderilor de sol (RUSLE) integrată în GIS a fost utilizată pentru a cuantifica pierderile de sol din marele bazin superior din Ziz (4435 km2) din sud-estul Marocului. Parametrii RUSLE au fost estimați pe baza datelor din imaginile din satelit, DEM-SRTM și studiile naționale ale bazinului hidrografic. Rezultatele arată că media anuală a eroziunii potențiale a solului este de 489,5 t. ha-1. yr-1 și volumul specific de sedimente este de 36,4 t. ha-1. yr-1. Principalele surse de sedimente se află în arealele din amonte și unele zone de depunere sunt situate înainte de zona de confluență. Aceste pierderi de sol contribuie la colmatarea anuală a barajului Hassan Eddakhil cu o rată de 3,5%. Aplicarea analizei principalelor componente la factorii de eroziune a solului arată o influență importantă a factorului de erodabilitate a solului (K), urmat de factorul topografic (LS), apoi de factorul de gestionare a culturilor (C). Aceste rezultate de modelare vor furniza date pentru Marele Atlas de sud-est marocan, importante pentru conturarea viitoarele proiecte de combatere a eroziunii a solului și pot fi un instrument util pentru propunerea strategiilor de conservare a solului.

Cuvinte-cheie: *eroziunea apei, RUSLE, teledetecție, SIG, bazinul Ziz, sud-estul Marocului*

Introduction

The southern Mediterranean areas, particularly Morocco, suffers enormously from the problems of soil erosion. According to the FAO's report, this phenomenon affects a large part of the national territory (up to 40%) (FAO, 2015). The cumulative annual soil losses are estimated at 100 million tonnes (Heusch, 1990), with 50 Mm3 of water lost each year by siltation in large dams.

In a semi-arid context such as the Ziz upper basin in south-eastern Morocco with poorly developed soils (Billaux and Bryssine, 1966), soil erosion and the deposition of sediment in rivers can be a major socio-economic problem endangering sustainable agriculture in small cultivated fields already vulnerable thereby increasing the rural exodus. The Hassan Eddakhil dam built in 1973 with an initial capacity of 380 Mm3 experiences a siltation rate of 1.47 Mm3.yr-1 (ABH-GZR, 2019). In fact, this basin was classified by the national watershed management plan (PNABV, 2001) among the 20 priorities. Thus, these results trigger the alert for an urgent intervention for better decision-making concerning the soil and water resources conservation in this basin.

The techniques used to estimate soil erosion (current and/or risk) vary according to the objectives, the means and the work scales. Soil erosion estimation can be done either by direct measurements or through indirect measurements.

Soil erosion modelling can be an appropriate tool. However, the choice of a particular model depends largely on the goal, the data and the time available. The availability of source data is an important selection criterion when assessing the erosion risk on a regional scale. Although a wide variety of models are available for estimating soil erosion, most require a lot of data for their input parameters, making their application at the regional scale difficult.

Therefore, there are different models to assess and quantify erosion rates on a large scale. Some are based on conceptual models, others on empirical or physical models. Among the empirical models, there is the revised universal soil loss equation (RUSLE) (Renard et al. 1997). This equation is the most used in the world (Merzouk et al. 1996) given that it is simple, easy, does not require much data and it can be easily integrated with GIS for better analysis. Thus, we applied the RUSLE model in this study for the large upper basin of Ziz.

The objective of this work is to estimate soil losses based on RUSLE using SRTM-DEM data, satellite imagery, geological and topographic maps of the upper watershed of Oued Ziz in southeast Morocco.

Description of study area and primary used data

The study area extends from the far east of the central High Atlas to the western part of the eastern High Atlas. It is part of the province of Midelt in the region of Draa-Tafilalet. Located upstream of the Hassan Eddakhil dam on Oued Ziz with an area of 4435 km^2 and a perimeter of about 613 km. It is between latitudes: 32°64'19'' and 32°05'48'' North and longitudes 05°46'20''and 04°11'72'' West.

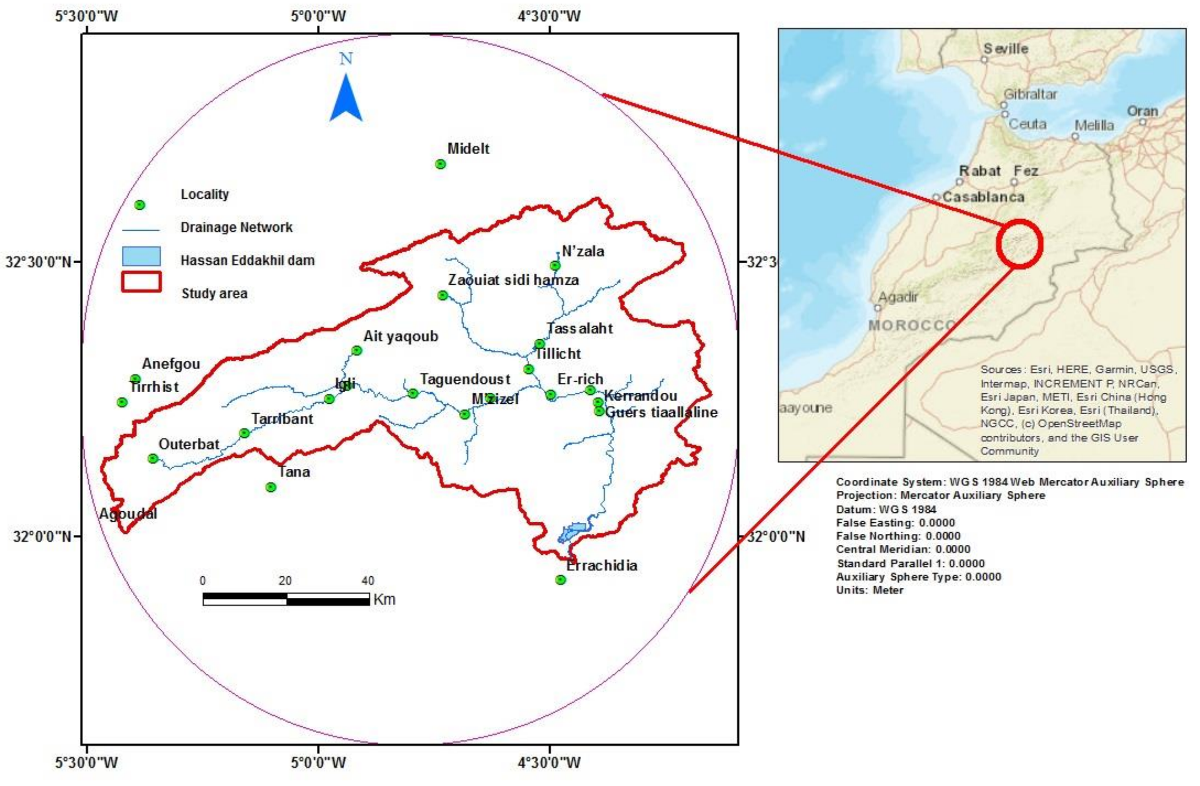

Figure 1: Localization of the Ziz upper basin in southeast Morocco

The Ziz basin topography is very hilly, the altitude varies from 1023 m (above sea level) in the catchment outlet to 3687 m in the north-western part (Fig. 5) with an average altitude of 1812 m. The hilly landscape represents a large part and the reliefs are characterized by steep slopes. The dominant slope class is between 0 and 15°, it represents 82%.

The Ziz upper basin climate is semi-arid, characterized by a harsh winter and a moderate summer with hot temperatures varying depending on the altitude. Annual precipitation ranges from 119 to 377 mm. Average annual temperatures vary between 19.2° C and 10.2° C. They are characterized by very high annual and daily amplitudes (respectively 50° C at Errachidia and 20° C upstream of the basin) (Navas et al. 2013).

For the soil analysis, we relied on the study carried out by the national watershed management plan (PNABV, 2014) of the Assif Melloul watershed, the adjacent basin on the west side of the Ziz upper basin.

The soils represented are almost little developed: eroded, alluvial or colluvial soils in deposit areas, or even raw minerals not yet developed on mountain peaks and rocky areas.

The geological formations of the study area are largely dominated by the Jurassic marl-limestone layers which extend over almost the entire area. In general, they are observed at two main levels of limestone: Upper Aalenian and Dogger (Charire, 1990; Hinaje, 1995; Sadki et al. 1999). The Triassic includes basalts, marls and dolomitic clays with salt levels. It occurs locally in small areas. Finally, the plio-quaternaries are characterized by continental backfill formations (Fig. 4) (PNABV, 2014).

The types of land use/land cover identified and reported on the maps in the Ziz upper basin are as follows:

• Agricultural fields: occupies the banks of watercourses;

• Water bodies: represented exclusively by the reservoir of the dam;

• Degraded forest: limited to the Atlas cedars, Phenician juniper, Thuriferous juniper, Holm oak and Aleppo pine and thorny xerophytes;

• Poorly vegetated areas (Rangeland): very largely dominant and very degraded with a scarcity of vegetation resulting from continuous irrational exploitation.

RUSLE model require five parameters as inputs of its equation. The topographic data was derived from an SRTM-DEM (the main input), The K factor was estimated using the Wischmeier monogram and the soil studies results of watershed management plan for the adjacent Assif Melloul watershed (PNABV, 2014). The R factor was calculated using rainfall data available from four meteorological stations. The C factor was estimated using the regression relation of Van Der Knijff et al. 1999 based on the NDVI index. NDVI map was extracted using satellite images of Landsat 8 (OLI) acquired in mars 2017. The table below provides more details on the data used in this study.

Table 1: Characteristics of the primary used data

Dataset	Year	Format
Monthly rainfall Data[1]	1976 to 2019	Digital excel
Geological maps[2]	1939 & 1956	Digital vector
Landsat 8 OLI[3]	2017	Digital raster
DEM – SRTM[3]	2017	Digital raster
Sedimentation record[1]	1973 to 2009	Digital excel
Google earth image[4]	2018	Digital raster
Soil textures[5]	2014	Digital excel

Source: [1]Guir-Ziz-Rhris watershed agency (ABH-GZR, 2019)

[2]Geological map of Midelt high Atlas (Gonzague et al. 1939) & Geological map of high Atlas north Ksar essouk and Boudenib (Lyazidi et al. 1956)

[3] www.earthexplorer.usgs.gov

[4] Google earth

[5] Watershed Management Plan Project: (PNABV, 2014)

Methodology and parameter estimation

Universal soil loss equation (USLE) is a model implemented by "Wischmeier & Smith" in 1978. It applies exclusively to inter-rill and rill erosion. It has been tested most widely around the world to predict long-term rates erosion (Dhman et al. 1997; Zouagui et al. 2018), and has given satisfactory results, on a large scale, and particularly in the Mediterranean region (Spain, Italy, Turkey, Tunisia, etc.) (PNABV, 2014). In Moroccan watersheds, several studies have achieved their objectives through this model. Therefore, this modeling approach remains an acceptable strategy for evaluating water erosion, especially if we consider the recent progress attributable to the RUSLE model, Revised USLE (Renard et al. 1997). This model is a multiplicative function of five factors according to the followed formula:

$$A = R.K.LS.C.P$$

where A is the mean annual soil loss (t. ha-1 yr-1), R is a rainfall erosivity factor (MJ mm. ha-1.h-1.

yr-1), K is a soil erodibility factor (t ha h ha-1 MJ-1 mm-1), C is a dimensionless cover and management factor, P is a dimensionless erosion control practice factor, LS is a topographic factor.

In this study, RUSLE is applied to the Ziz upper Basin by representing the basin as a grid of square cells and calculating soil erosion for each cell. RUSLE model compute the average annual soil loss expected on field slopes using an Equation of five parameters. The approach used in this work is schematized below.

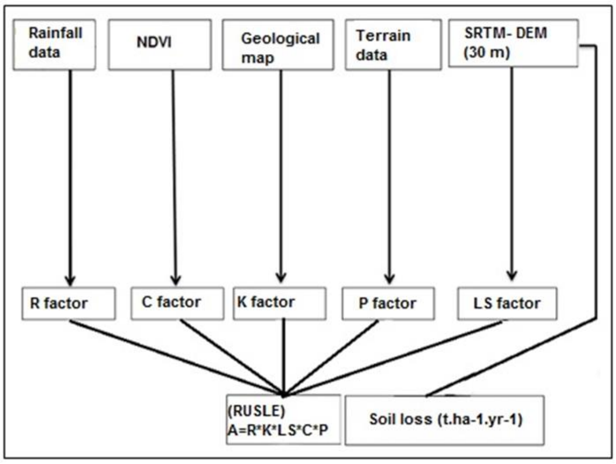

Figure 2: Methodology flow chart

The application of RUSLE model for Ziz upper basin requires the preparation of five thematic maps, each representing one factor of RUSLE equation. Once database was created, we chose a resolution of 30 meters corresponding to the DEM -SRTM resolution. Integration of these maps in GIS allowed us to obtain a potential soil erosion map.

Rainfall erosivity factor (R)

Rain kinetic energy contributes strongly to the detachment of soil particles and it depends on the size and the drops fall rate. However, this size and speed are greater the more intense the rains. This energy is directly linked to the rain intensity.

The estimation of R factor according to Wischmeier & Smith (1978) formula requires knowledge of the kinetic energy and rain average intensity.

In the present study, monthly rainfall data were used to calculate the R factor from the following formula developed by Rango & Arnoldus, 1987:

$$Ln(R) = 1.74 \log \Sigma \frac{Pi2}{Pi} + 1.29$$

Where:

R is rainfall erosivity (MJ mm ha -1 h -1 yr-1) and Pi is monthly rainfall (mm) and P is annual rainfall (mm).

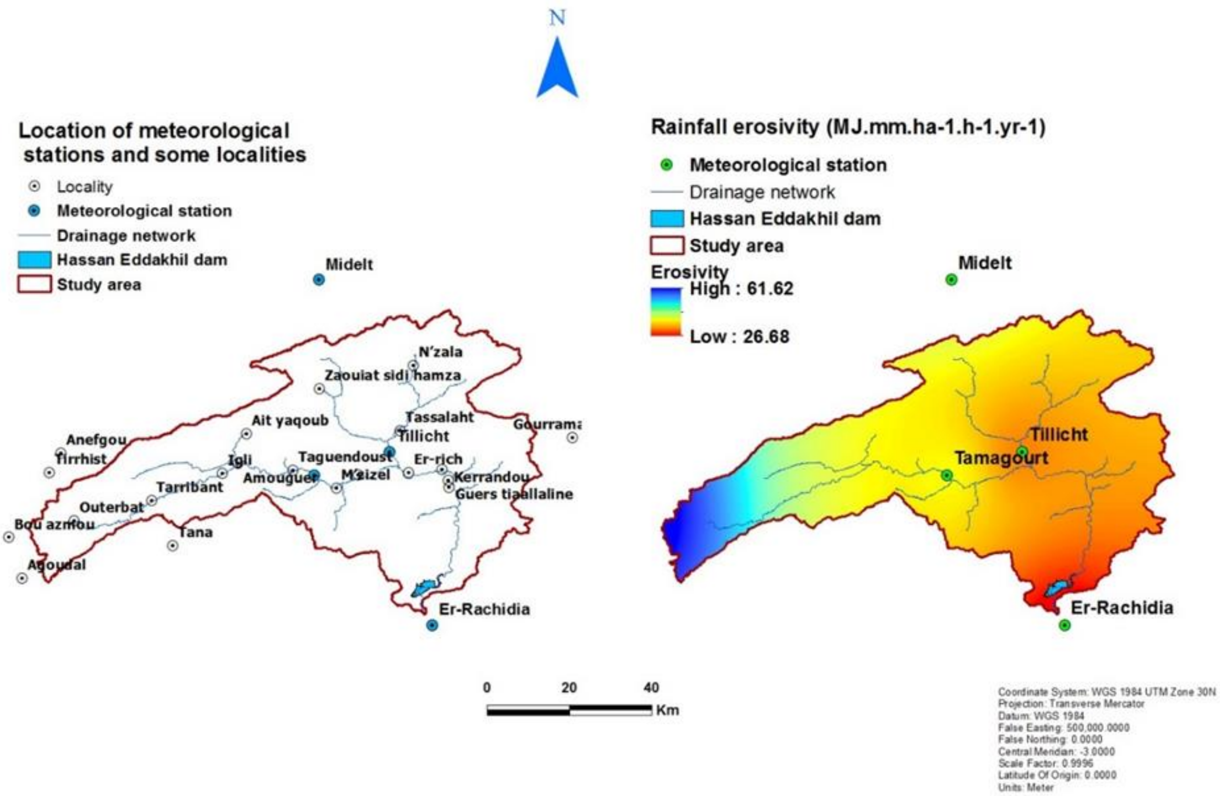

Figure 3: Location of the meteorological stations (left) and R factor map (right)

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Soil erodibility factor (K)

This parameter measures the susceptibility of soil particles to detachment under raindrops impact or runoff or a combination of both. Soil physical parameters, particularly organic matter, clay, structure and permeability, are decisive for keeping tolerable erodibility rates.

The K factor parameters were estimated based on the results of the national watershed management plan (PNABV, 2014) by using the following Wischmeier equation:

$$100K = 2{,}1.M^{1{,}14}.10^{-4}(12-a) + 3{,}25\,(b-2) + 2{,}5\,(c-3)$$

Where:

K: Soil erodibility factor (t ha h.ha-1.MJ-1.mm-1) and M = (% silt + % fine sand) * (100 -% clay).

a: percentage of organic matter, b: soil structure code (1 to 4) and c: permeability code (1 to 6)

Faced the presence of coarse elements in the soils, we used the adjusted K factor according to the formula of Dumas et al. 1964, as follows:

Kajusted = K. (0,983 – 0,0189 X + 0,0000973 X2)

Where:

K: Wischmeier erodibility factor and X: The percentage of coarse surface elements having a size of more than 2mm.

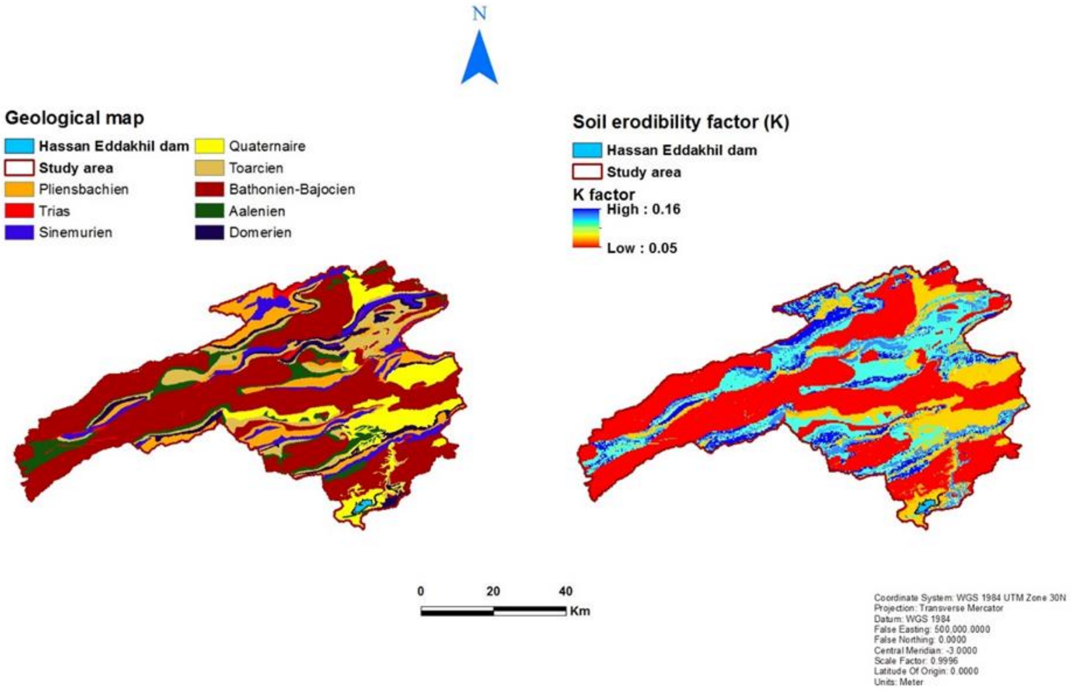

Figure 4: Geological map (left) and Soil erodibility factor map (right)

Topographic factor (LS)

Topographic analysis is essential in understanding the erosive behavior of a watershed. Where the plant cover is absent, the topography becomes decisive in the different phases of the erosion process, especially the sediment transport phase.

The two topographic parameters that control erosion are the slope length and the gradient of the slope. The more their values increase, the more active the erosion on the slopes, and the higher the runoff, hence the high risk of flooding (Roose, 1977).

The slope length factor was evaluated using the following formula of Wischmeier and Smith, developed by Bizuwerk et al. 2003:

$LS = (L/22{,}13)^{m} .(65{,}41\ Sin^{2}(S) + 4{,}56\ Sin(S) + 0{,}065)$

Where:

L is the Slope length (m). L= flow accumulation × DEM spatial resolution and S is the slope gradient (in %).

m: Constant which is equal to: 0.5 for slopes greater than 5%; 0.4 for slopes of 3.5 to 5%; 0.3 for slopes of 1 to 3.5% and 0.2 for slopes of less than 1%.

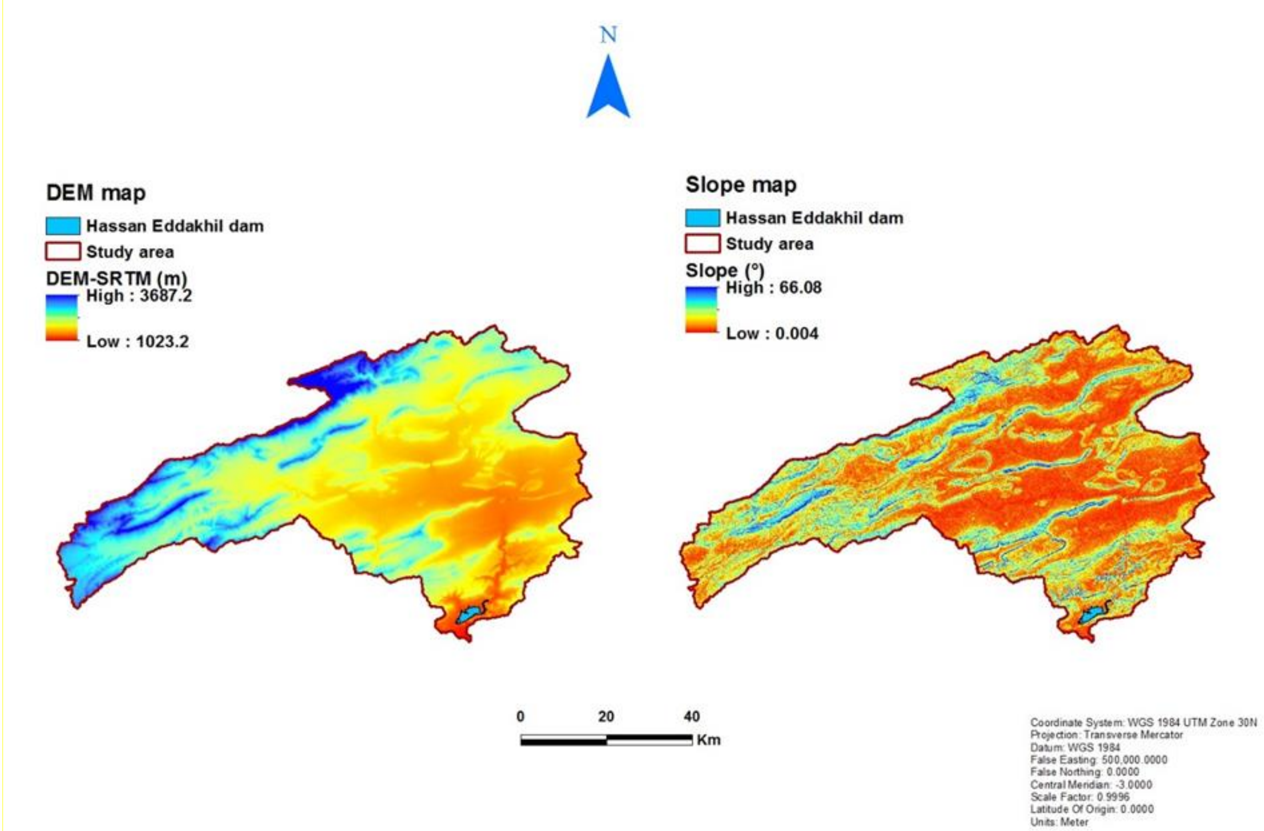

Figure 5: DEM map (left) and Slope map (right)

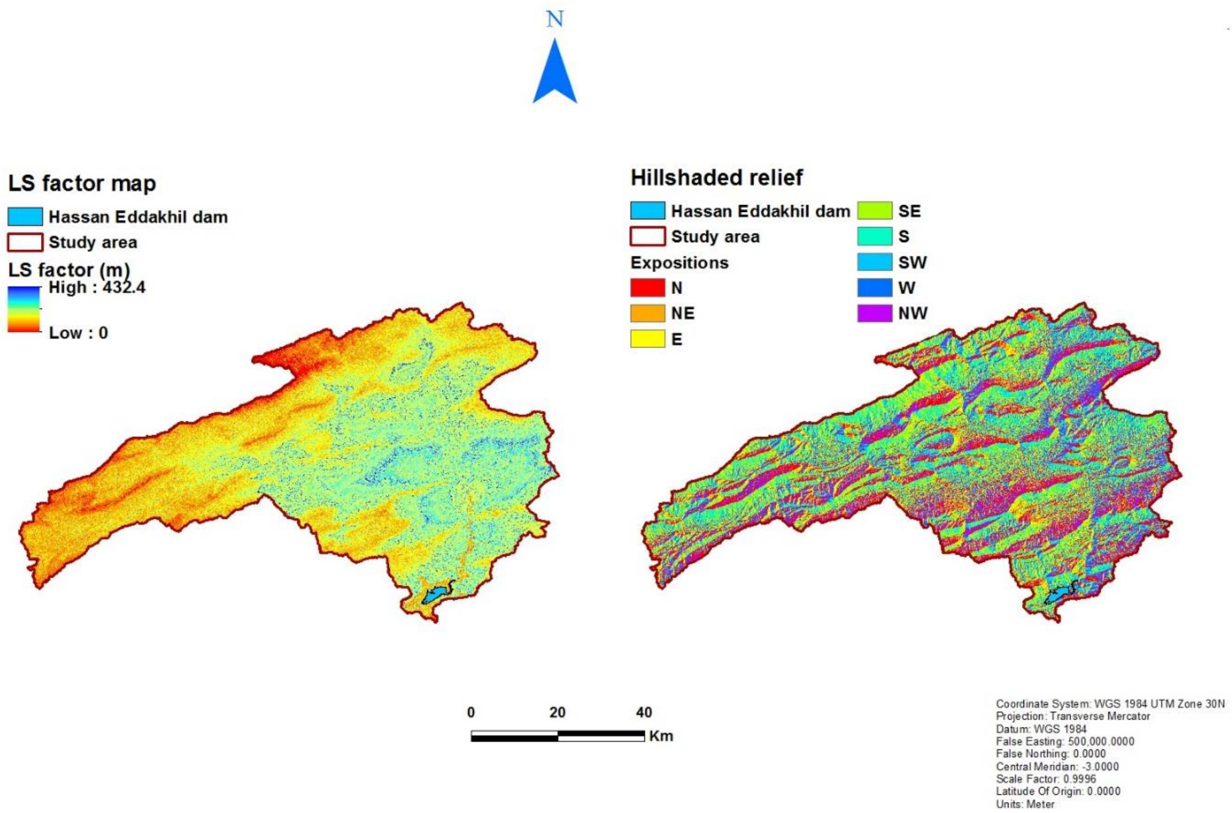

Figure 6: LS factor map (left) and shaded relief map (right)

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Crop management factor (C)

Land cover is a key parameter in predicting the rate of erosive activity. Indeed, this parameter, which plays in an interval varying from 0.001 (well-covered soils) to 1 (bare soils), has great utility in protecting the soil against the "splash" effect of rain droplets, and in improving infiltration depends on runoff. This factor depends on several criteria: the coverage duration (all year round or a few months), the coverage rate, the type of plant foliage (plant architecture), the restitution of cultures… Etc.

The cover rate is calculated following the application of the NDVI (Normalized Difference Vegetation Index) to the satellite imagery used. This NDVI index is calculated as a ratio between the values of the red band (R) and the near infrared band (NIR), which reflects the fraction of the synthetically active photo radiation absorbed.

$$NDVI= (NIR - R) / (NIR + R)$$

For Landsat8 OLI images, NDVI is calculated using the following equation (Barsi et al. 2014):

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4)$$

The C factor can be estimated by applying the following regression relationship (Van Der Knijff et al. 1999):

$$C = \exp[-\alpha*(NDVI/(\beta-NDVI))]$$

Where:

α, β: Parameters determining the shape of the NDVI-C curve, with α = 2 and β = 1.

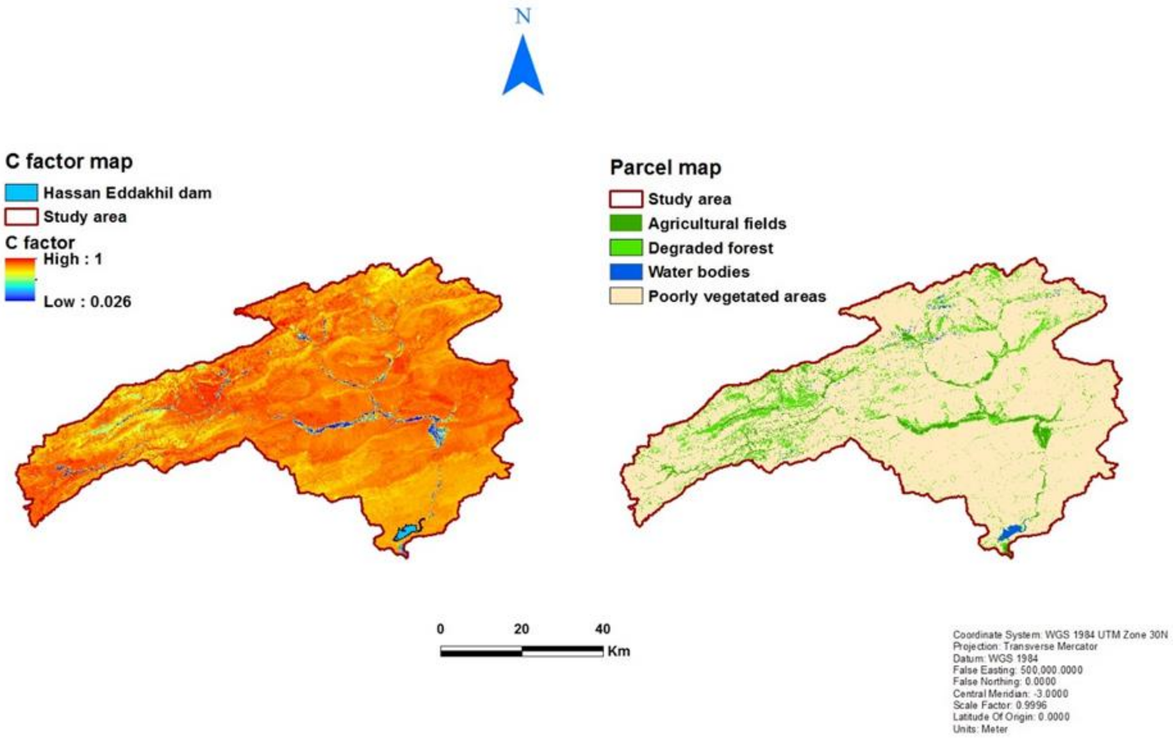

Figure 7: C factor map (left) and Land use/Land cover map (right)

Conservation support practice factor (P)

It is a parameter that allows consideration of existing anti-erosion facilities in the estimation of soil losses from watersheds. Each of these measures has a degree of protection, the coefficient of which is established according to its effectiveness in reducing runoff or mitigating sources of erosion.

Among the most effective soil conservation practices, we cite the crops in contour lines, in alternating strips or in terraces, reforestation in benches, hilling and ridging. The values assigned for this factor are less than or equal to 1. This maximum value is assigned to land on which none of the cited practices are used.

Sediment yield and dam's siltation rate

Sediment yield (SY) is the quantity of sediment arriving at the outlet of the watershed. To assess this quantity, it is imperative to calculate a sediment delivery ratio (SDR). In this study, the SDR coefficient defined by Hession and Shanholz (1988) was used according to the following equation:

$$\mathrm{DR} = 10(\frac{\mathrm{D}}{\mathrm{L}})$$

Where:

DR: delivery ratio, D is the elevation difference in the basin (m) and L is the length (m) of the main talweg in the basin.

Thus, the sediment quantity delivered to the outlet is calculated by the following equation:

$$\mathrm{SSY} = \mathrm{SDR} * \mathrm{A}$$

Where:

SSY is the specific sediment yield (t. ha-1. yr-1), SDR is the sediment delivery ratio and A is the potential soil erosion (t. ha-1. yr-1).

Results and Discussion

Rainfall Erosivity Factor (R)

Meteorological stations of the Ziz upper watershed record only average monthly and annual rainfall data. Thus, the alternative formula was applied. Spatial distribution of R factor in the study area was estimated by calculating R for each station, then extrapolating by the interpolation method IDW (Inverse Distance Weighted), which allow to estimate the values of any point.

The rainfall erosivity map was developed based on four meteorological stations datasets, located in the watershed. These datasets contain both annual and monthly average rain as described in the figure 3. The R factor value ranges from 26.6 to 61.6 MJ mm. ha-1.h-1. yr-1. Low values occupy the south and the east parts. However, high values are observed in the west watershed borders. The highest values are located in the western and northwestern parts, representing respectively the upstream mountainous areas in the Ziz upper watershed.

The rainfall erosivity is homogeneous. The class between 30 and 40 which dominates over more than 79% of the basin. In general, this factor occurs strongly upstream (mountainous part) whose main precipitation falls in the form of thunderstorms especially in autumn, which previews its major role in the generation of erosive processes.

Soil Erodibility Factor (K)

Given the absence of a soil study in our study area, we estimated the K factor parameters based on the results of the national watershed management plan (PNABV, 2014) for the Assif Melloul basin, adjacent to our study area where the pedogenetic conditions are similar.

The K factor was determined by combining three maps: geological maps, land use map and slope map. For each homogeneous unit, we assigned its corresponding K factor. Thus, the sites sampling and observation were chosen based on the homogeneous units map, developed from the superposition of the three maps. These homogeneous units were prospected to estimate the parameters of the structure, the permeability, the organic matter and to take some samples for granulometric analysis.

The presence of coarse elements in the soils is common in our study area where several rock outcrops are observed on the slopes and especially on the limestone and marl-limestone peaks. Faced with this situation, we used the adjusted K factor formula. Because, the presence of coarse elements on the soil surface plays a considerable role in the soil protection this requires the adjustment of the K factor.

According to the adjusted values, K factor vary between 0.05 and 0.16 t.ha.h. ha-1.MJ-1.mm-1. The soil erodibility follows the same spatial distribution as in the geological map.

Topographic Factor (LS)

Topographic analysis is essential to understand the erosive process for any watershed. Where the plant cover is absent, the topography becomes decisive in the different phases of the erosion process, especially the sediment transport phase. The two topographic parameters that control erosion are the slope gradient and the slope length. The higher their values, the more active the erosion on the slopes, and the higher the runoff, hence the high risk of flooding.

The LS factor values vary between 0 and 432m. The spatialization of this factor shows that the large part of the basin (87%) display values between 100 and 250m. The longest slopes are observed on the less rugged reliefs, especially the depressions which line the wide beds of Ziz valley.

Cover Management Factor (C)

In the Ziz upper basin, five class of land cover/land use are reported: rangelands or poorly vegetated areas, agricultural fields, water bodies, built-up area and degraded forest.

The C factor of the ziz upper basin generated from the NDVI index (Fig. 6) vary between 0.026 and 1 with an average value of 0.82, which means that land cover rate is very low. This implies that the plant cover is almost absent and cannot reduce the rate of water erosion because the soils are exposed to the detachment and transport of sediments. Only agricultural fields that occupies small plots on the watercourses banks which offer good to medium coverage with C factor values less than 0.3.

Support Practice Factor (P)

The P factor is a parameter that allows consideration to anti-erosion practices in the estimation of soil losses from watersheds. Each of these measures has a degree of protection, the coefficient of which is established according to its effectiveness in reducing soil erosion rate. In the Ziz upper watershed, no significant conservation practices have been taken to reduce the soil loss rate apart from cultivated fields, where some unprotective practices have been planted such small terraces. So, in this study, P values were 1 because soils in general are without any support practices; unprotected soils represent more than 90% and 10% who remain with non-protective practices. The different LULC classes in the Ziz upper basin are mentioned in the following table.

Table 2: Distribution of LULC classes in the Ziz upper watershed

LULC class	Description	Area (%)
Water bodies	Represented exclusively by the reservoir of the dam	0.6
Agricultural fields	Occupies the riverbanks of Oued Ziz	10.1
Degraded forest	Limited to Atlas cedars, Phenician juniper, Thuriferous juniper, Holm oak and Aleppo pine and thorny xerophytes	25.1
Built-up area	Residential, commercial and services, industrial, socio-economic infrastructure and mixed urban and other urban, transportation, roads and airport	0.5
Poorly vegetated areas (Rangeland)	Very largely dominant and very degraded with a scarcity of vegetation resulting from continuous irrational exploitation	64

Soil erosion map and main sources of sediment

Potential soil erosion map has been prepared by the combination (overlay operation) of five thematic maps representing RUSLE factors, which are rainfall erosivity (R factor), soil erodibility (K factor), topographic factor (LS), vegetation cover (C factor), and soil conservation practices (P factor). The integration and processing in a GIS Environment (ArcGIS 10.5) of these five factors led to the development of a map indicating the potential erosion in each pixel at the Ziz upper basin. This map allows us to have a spatial distribution of erosive risk. The potential soil erosion (Figure 9) ranges from 0 to 2400 t. ha-1. yr-1, with an average of 489.5 t. ha-1. yr-1.

To better understand the soil erosion map, we have subdivided the Ziz upper basin using the "Watershed" option of the GIS Idrisi into 27 sub-basins.

According to sub-basins soil erosion results, the high values of soil erosion seems probably biased. But, the soils in the Ziz upper basin have disappeared which has led to the outcropping of the bedrock on almost all the slopes, which transforms it into a slab form amplifying the runoff and favoring the floods generation even in light rain.

The soil erosion map has been classified into four classes using the same soil classification of Sadiki et al. (2004) which assumes that soils can tolerate losses of up to 7.41 t. ha-1. yr-1 to describe soil loss intensity and to display both susceptible areas to erosion and areas of deposition; these classes are as follows:

Table 3: Distribution of soil losses class in the Ziz upper catchment

Class	Interval	Potential erosion risk	Area (ha)	Area (%)
I	< 7	Low	5748.75	1.3
II	7 - 20	Moderate	2440.71	0.6
III	20 - 70	High	229425.84	51.8
IV	> 70	Very high	204946.83	46.3

According to soil erosion classes, very high losses were recorded in all the sub-basins where 98% of the Ziz upper basin show high to very high erosion class, 0.3% present moderate erosion and 1.3% display slight erosion.

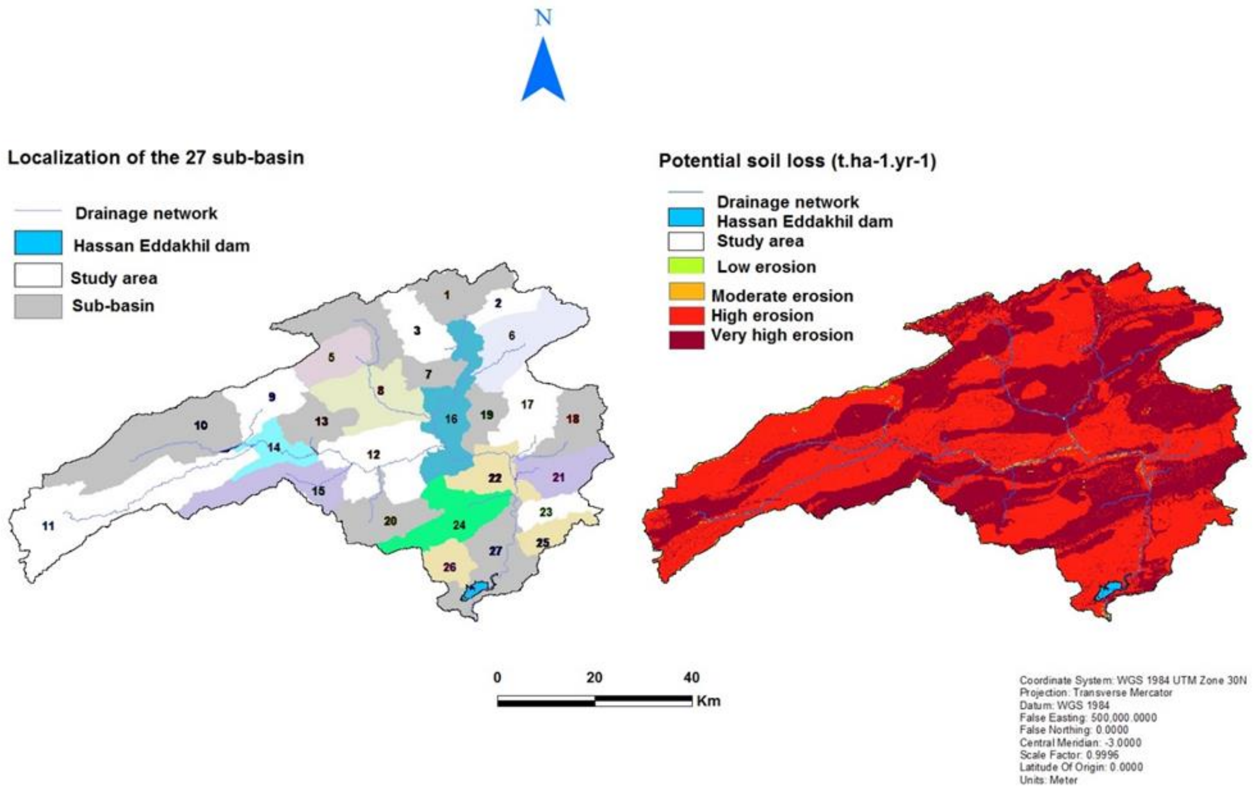

Figure 8: Sub-basins of Ziz upper watershed (left) and potential soil loss map (right)

Sediment yield and siltation rate of the Hassan Eddakhil dam

According to SDR result, the sediment yield was estimated at 16,143,400 t. yr-1 and the specific sediment yield of 36.4 t. ha-1. yr-1 for this basin.

Table 4: Caracteristics of Ziz upper watershed used to calcul SDR and SSY and SY.

Watershed	Area (ha)	L (km)	D (m)	SDR	SSY	SY
Ziz basin	443 500	172.6	2664	0.15	36.4	16143400

Where:

SSY: specific sediment yield (t. ha-1. yr-1); SY: sediment yield (t. yr-1); SDR: sediment delivery ratio and L: length (km).

Based on Ghorbel's (1977) results "one cubic meter of mud with an apparent density (da) = 1.7 contains 1.2 tons of solids (sediments)". So, the sediment load arriving at the Hassan Eddakhil dam can also be expressed as 13452833 m3. yr-1. The dam's reservoir has a capacity of 380 million m3. So, sheet erosion will contribute annually to 3.5% of the dam siltation, giving a dam lifespan of 30 years and assuming that suspended sediment doesn't leave the dam reservoir.

Impact of each factor on the soil erosion process

The factors controlling soil erosion act differently in the Ziz upper watershed. Indeed, the soil erodibility factor remains the most influenced in triggering erosion, since the correlation between this factor and soil erosion is significant (89%). It is therefore a good indicator of soil erosion. Then, the two factors LS and C, they have a correlation with soil erosion of 68% and 67% respectively. However, the factor R is less significant (61%).

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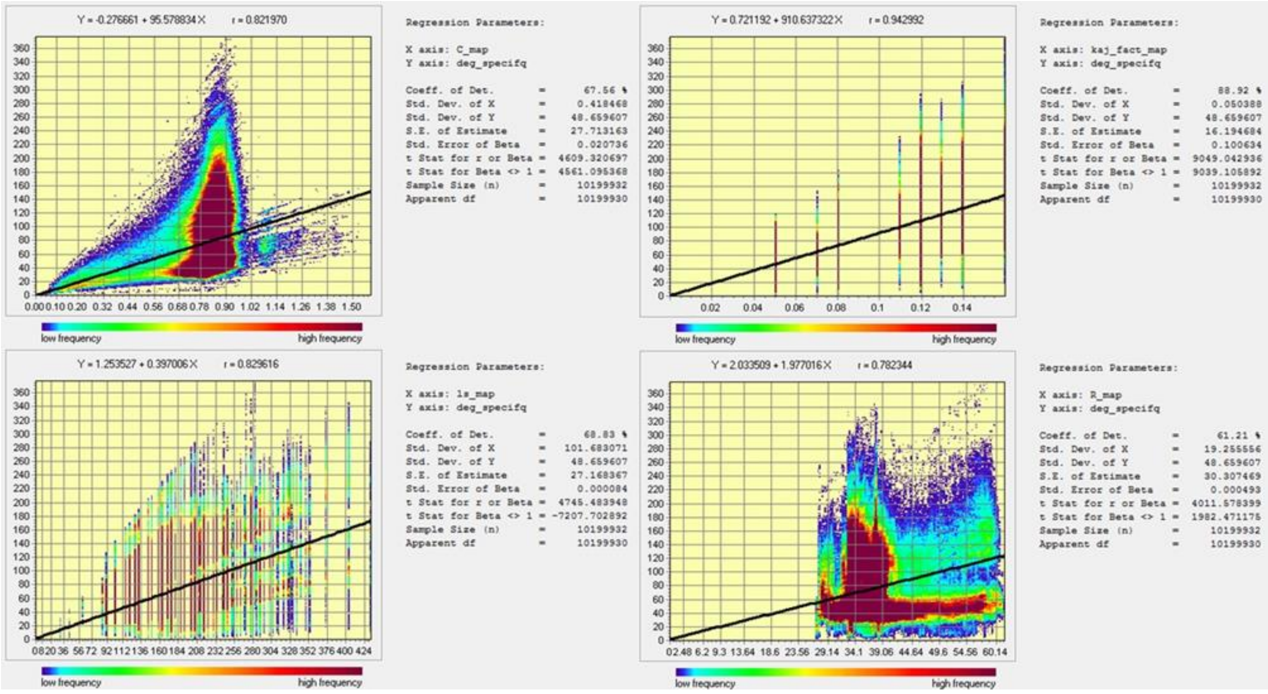

Figure 9: Statistical analysis of the erosion production factors in the upper Ziz basin

Conclusion

This study highlights the impact of water erosion threatening the Ziz upper watershed in the oriental High Atlas. Empirical soil erosion models such RUSLE are relatively simple, easy and require minimal data. The RUSLE equation combined with GIS and remote sensing plays an important role in producing the soil loss map. According to the Potential soil erosion map, more than half of the study area present a potential erosion values exceeding 400 t. ha-1. yr-1. The annual average soil loss is about 489.5 t. yr-1 that giving rise to the average specific sediment yield of 36.4 t. ha-1. yr-1. The sediment source zones are mainly located in the upstream parts with steep slopes which receive significant precipitation.

The soil loss map can constitute for the managers and planners a good tool in order to conserve the areas of priority and preserve or manage potential areas to the erosion risk.

According to the PCA results, the K factor is the most controlling in the erosion process (0.89) followed by the two factors LS and C, their coefficients of determination are 0.68 and 0.67 respectively. The R factor remains the least controlling in soil erosion (0.61).

The RUSLE model, remote sensing and GIS are simple and inexpensive tools to assess soil erosion for large inaccessible areas where field measurements are rare or even non-existent.

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