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Study of the vulnerability of the Bouregreg basin to the risk of water erosion

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Abstract – – Water erosion is a major agronomic, economic and environmental concern in semi-arid Mediterranean environments. The choice of method to estimate it depends on the data available and the conditions of the study area. Located in north-west Morocco, with a surface area of 9971.54 km2, the Bouregreg basin suffers from the phenomenon of water erosion.

The aim of this study is to investigate and quantify water erosion in this basin by applying the RUSLE model integrated with remote sensing and a Geographic Information System. An exhaustive study of the study area was carried out in order to characterize the main factors involved in the evolution of water erosion in the Bouregreg basin. The results of this study demonstrated that the simultaneous presence of watercourses running through easily erodible areas, as well as steep slopes with no plant cover, aggravate this phenomenon and exert a control over its evolution.

The results obtained by the RUSLE model indicate an estimated average soil loss of 4.9 t/ha/year, with a minimum of 0 t/ha/year and a maximum of 89.4 t/ha/year. Furthermore, comparison of the soil loss estimates obtained in this study with those from previous work reveals relatively minor differences.

Keywords – Erosion; Bouregreg Watershed; RUSLE; Remote Sensing; GIS; Soil; Dégradation Des Sols

I. Introduction

The Bouregreg watershed is among the Moroccan basins experiencing water erosion, leading to annual soil losses that disrupt the natural balance of the basin's ecosystems and hinder the socio-economic development of the region. These soil losses are particularly evident around the Sidi Mohamed Ben Abdellah Dam, located near the mouth of the Bouregreg, causing estimated sedimentation costs in the millions of dirhams annually and resulting in significant financial consequences.

Over the past decades, estimating soil erosion using empirical models has been a promising research area. However, applying these models to large, unmeasured areas remains a genuine challenge due to the availability and quality of required data.

In this context, the present study aims to estimate the rate of water-induced erosion and map erosive risks in the Bouregreg watershed using the Revised Universal Soil Loss Equation (RUSLE) model, aided by remote sensing and geographic information systems (GIS).

II. Materials and Method

1. Study area

The studied Bouregreg watershed is situated in the northwestern part of Morocco, spanning between 5.4–6.8°W and 32.8–34°N (Fig.1). It is a component of the larger Bouregreg Chaouia basin, covering a perimeter of 700m and a total area of 9971.7km2, which also includes the Sidi Mohamed Ben Abdellah Dam (SMBA) area. The watershed exhibits an elliptical shape and occupies almost the entirety of the central Moroccan plateau, extending partially into the Rabat-Salé region, as well as the provinces of Khénifra and Khémisset.

The sector is bordered by the Oued Oum Er-Rbia basin and the coastal river basins (Cherrat, Ykem, N'Fifikh, and Malleh) to the south and southwest, by the Oued Sebou basin to the northeast, and opens westward towards the Atlantic Ocean.

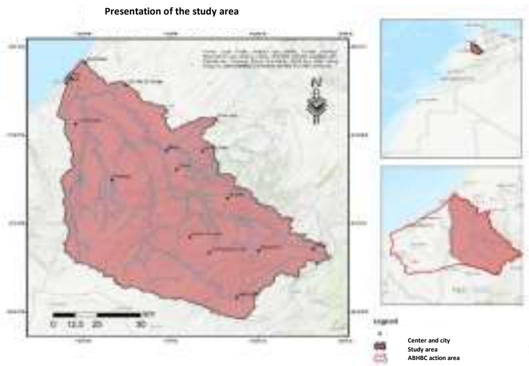

Figure 1: The study area

2. Methods

To assess soil water erosion in the Bouregreg watershed, the (RUSLE) model was specifically chosen for this study due to its ease of application and compatibility with geographic information systems. The RUSLE is expressed by ((Wischmeier and Smith, 1978)[1] ;(Renard et al., 1997)[2]) :

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

Where:

A is the estimated soil loss,

R is the precipitation erosivity factor,

K is a soil erodibility factor,

L is slope length factor

S is the slope inclination factor,

C is a cover management factor

P is a supporting practices factor.

2.1 Determination of erosion parameters

a. The erosivity index R

The Rainfall Erosivity Index (R) is considered a key variable for predicting the climate's impact on erosion. During his work in Morocco, Arnoldus (1977)[3] developed an iso-erosion map in the metric system using the following relationship:

$$R= 0.264 \times (FA)^{1.50}$$

$$FA= \frac{\sum_{i=1}^{12} {P_i}^2}{P}$$

Where:

- FA: is the Fournier-Arnoldus Index or modified Fournier Index, calculated as
- Pi : represents the average monthly precipitation (mm),
- P: is the average annual precipitation (mm).

In this study, this index is used to calculate the climatic aggressiveness factor R, utilizing precipitation data from 13 pluviometric stations covering the Bouregreg study area.

b. LS factor

The LS factor was calculated using the equation of (David 1987)[4]:

This equation is more appropriate since it provides more realistic values for this watershed, thus enabling a better estimate of the LS factor.

$$LS = 0,10 + 0,12 \times S \times 4/3$$

c. C factor

The C factor compares soil losses on land well covered by dense natural vegetation, those on bare land with no vegetation cover and those under specific management (Wischmeier and Smith, 1978). The value of C varies from close to zero for well-protected soils to 1 for striated surfaces highly susceptible to water erosion (Angima et al, 2003)[5]. For this study, the C factor was determined on the basis of the categories of the land use map for the year 2022 for the Bouregreg basin, obtained by processing and classifying Sentinel-2 satellite images.

Determining the C factor involves assigning specific values to different land use types, based on C values recorded in the same region.

d. K factor

Soil erodibility K characterizes a soil's resistance to erosion. The K factor is essentially linked to soil characteristics such as texture, presence of organic matter and permeability. This factor is determined by soil type.

Repeated experiments on different soil types led Wischmeier and Smith (1978)[1] to develop an equation for calculating soil erodibility:

$$K = \frac{\left((2.1 \times 10^{-4} \times M^{1.14}) \times (12 - a) + 3.25 \times (b - 2) + 2.5 \times (c - 3)\right)}{100}$$

With:

M= (% fine sand + % silt) × (100 - % clay)

a : Percentage of organic matter

b: Permeability code (fast: 1; moderate to fast: 2; moderate: 3; slow to moderate: 4; slow: 5; very slow: 6)

c: Structure code

e. P factor

The P factor, expressed as a dimensionless coefficient, is used to assess the effectiveness of anti-erosion practices in preserving water resources and conserving soil, P-factor values are determined, ranging from 0 to 1. Values closer to 0 indicate an erosion-resistant environment, while a value of 1 indicates the absence of anti-erosion measures.

The estimation of this factor is based on the method developed by Shin (1999)[6], which enabled us to obtain an estimate of this factor as a function of slope.

III. RESULTS

1. Factor Maps

The majority of the Bouregreg watershed territory experiences high rainfall aggressiveness, as this index ranges from 50.29 Mjmm/ha/year to 122.37 Mjmm/ha/year, with an average of 83.59 Mjmm/ha/year. The LS values range from 0.1 to 17.42, with the highest values primarily observed in the highlands and along the slopes of three rivers (Bouregreg, Grou, Koriffla), consistent with the digital elevation model and the geological formations that flank them.the value of soil erodibility factor (K) value varies from 0.01 to 0.08 depending on the characteristics of each soil. The K index increases from 0.01 to 0.019 for the less sensitive soils, such as sandy hydromorphic soils with ferruginous concretions and red soils on Paleozoic, to 0.042 and 0.08 for the most fragile soils. It is evident that a significant proportion of the soils in the Bouregreg watershed is highly prone to erosion; in fact, 51.5% of the soils have an erodibility index between 0.042 and 0.08. The values of the C factor in the watershed range from 0 to 1, with areas devoid of vegetation having a high C factor, occupying more than 75% of the basin's surface and thus promoting erosion. In contrast, there are areas where vegetation is present, with lower values of the C factor. The P factor ranges from 0.55 to 1, with 0 assigned to areas strongly resistant to anthropogenic erosion due to effective support practices, while 1 is assigned to vulnerable areas characterized by steep slopes and the absence of anthropogenic support practices.

2. Potential Soil Erosion Rates of Bouregreg watershed

The multiplication of the five factors mentioned above (R, K, LS, C and P factors) led to the production of a soil loss map for the study area (fig.2). The results of this map indicate an erosion variation ranging from 0 to 89.4 tonnes per hectare, with an estimated average annual soil loss of 5 tonnes per hectare per year.

Soil loss map in the Bouregreg basin

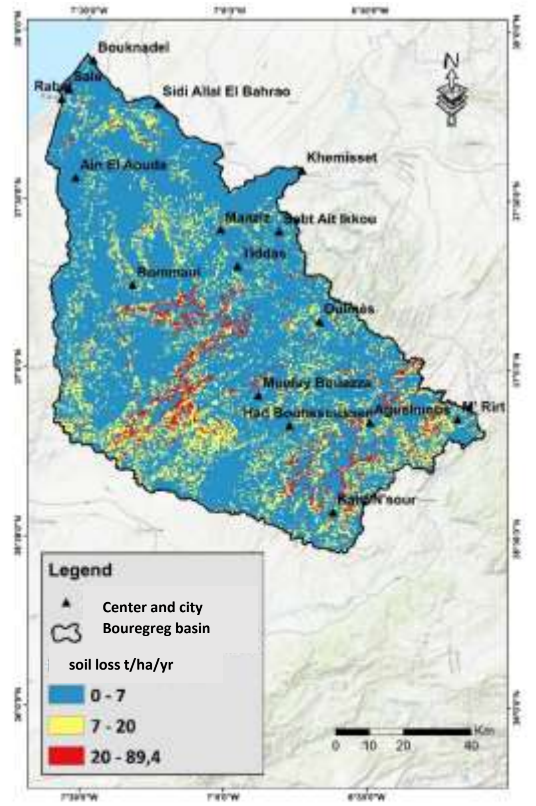

Figure 2:Soil loss map in the Bouregreg basin

IV. DISCUSSION

The visualization of the soil loss estimation map shows that the distribution of erosive risk in the study area varies from one zone to another in the watershed, depending on the influence of various explanatory factors such as soil characteristics, type and rate of vegetation cover, topography, climatic aggressiveness, etc.

Areas with losses below the limit of 7 tonnes per hectare per year are mainly found in the plains of the watershed and in mountainous regions characterized by steep slopes and a moderate to high R erosivity index. The low observed erosion can be explained by the low erodibility of the soils (k=0.019) present in these areas.

On the other hand, classes of high, or even very high, erosion are mainly located in areas characterized by a low or absent vegetation cover associated with steep slopes, and poorly evolved soils with high erodibility reaching 0.08 t/ha/ha/MJ/mm.

V. CONCLUSION

This study presents the results of quantifying soil losses in the Bouregreg basin using the empirical Revised Universal Soil Loss Equation (RUSLE) model. The use of geographic information systems and remote sensing enabled us to identify and combine the various factors involved in erosion processes.

The results obtained show that the Bouregreg basin is subject to a highly aggressive climate, which has a strong influence on soil erosion, with very high erodibility and no vegetation cover.

This study shows that, whatever the climatic aggressiveness, slope or soil type, the intensity of erosion depends mainly on the vegetation cover, which acts as a protective inking against the various agents that control erosion.

Analysis of the results of the RUSLE model shows that the Bouregreg basin is not subject to much erosion. The average value of soil loss (t/ha/year) obtained in the Bouregreg basin is 5, with a minimum of 0 and a maximum of 89.4. However, it should be noted that the RUSLE model is only interested in sheet and gully erosion, so the water erosion rate must be higher than the results obtained.

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