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Research Article

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Contribution to the study of soil vulnerability to water erosion on the Thiès plateau

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Abstract The aim of this work is to contribute to the study and modelling of water erosion in the Thiès plateau using the Universal Soil Loss Equation (USLE) model. The implementation of the USLE model has made it possible to define with greater precision the areas most at risk from erosion, using data on topography, land use, climatology and pedology.
Analysis, data combination and modelling were carried out using a Geographic Information System (GIS). Each factor is a numerical estimate of a specific component affecting the severity of soil erosion at a given location.

Keywords water, soil, erosion, modeling, Thiès plateau, USLE

Introduction

Soil degradation is defined as the process of reducing soil productivity or the quality of natural resources.
In temperate countries, it takes 25 years (i.e. one human generation) to form one meter of topsoil from rock, which is enough time to erode the soil into bedrock. [1]
In Senegal, climatic variability has largely affected soils. In our study area, the villages are located in the commune of Notto and Tassette, this part of the Thiès plateau is under the influence of water erosion due to runoff.
The aim of this work is to model the erosion phenomenon using the Wischmeier method,

Description of the Study Area

The Thiès plateau is located in western Senegal, in the Senegal-Mauritania sedimentary basin. The entire Thiès Plateau area is an ecosystem made up of three massifs (Diass, Thiès and Mont-Rolland), each characterized by a chain of hills of varying dimensions.
The study area is located in the commune of Notto and Tassette, forming the southern edge of the Thiès plateau.

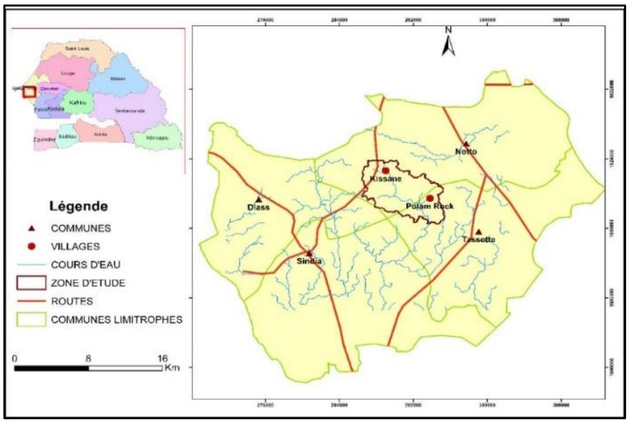

Figure 1: Location map of study area

Materials and Methods

Quantification of soil losses due to water erosion

Soil losses due to water erosion were quantified using the Revised Universal Soil Loss Equation (RUSLE): A = R . K . LS . C . P. (1)

Application of the RUSLE requires evaluation of the various factors of the universal equation over the entire catchment area, and their expression in the form of thematic maps. These maps are integrated into a geographic information system using spatial analysis tools [4].

By cross-referencing the maps and applying the mathematical equations of the Wischmeier & Smith model, it is possible to assess the rate of erosion at all points in the study area, and draw up a synthetic soil loss map according to the methodological flowchart shown in the following figure.

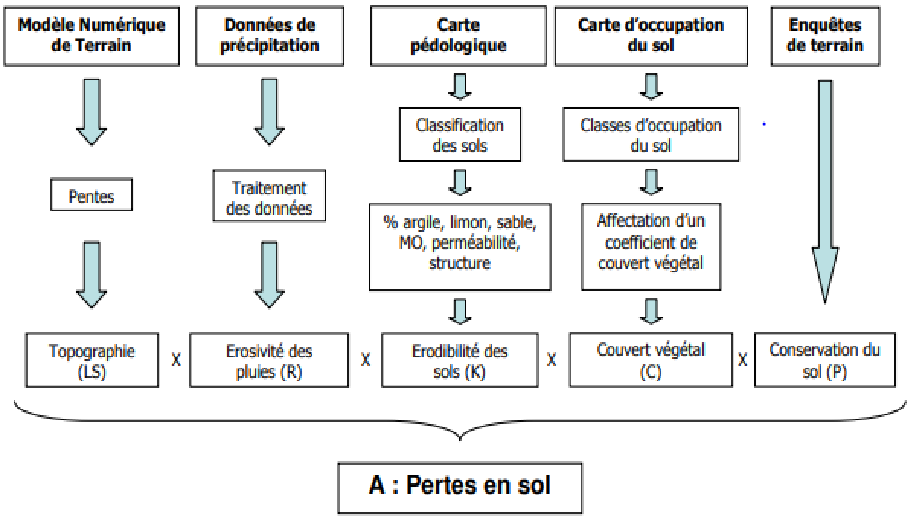

Figure 2: Methodology diagram

Results and Discussion

Geometrical characteristics

The basin has a perimeter of 38.89 Km and a surface area of 43.21Km2. The compactness index is 1.7, reflecting the elongated shape of the basin. For the equivalent rectangle, the length and width are 16.9 km and 2.6 km respectively. Consequently, the gully density is 3.59 km2/km.

Calculating climatic erosivity (R)

Rainfall erosivity was calculated according to the FOURNIER equation modified by ARNOLDUS [3] using monthly rainfall from September to August for the period 2000/2019 at rainfall stations located in the Thiès region. The distribution map of the R factor is shown in the figure below

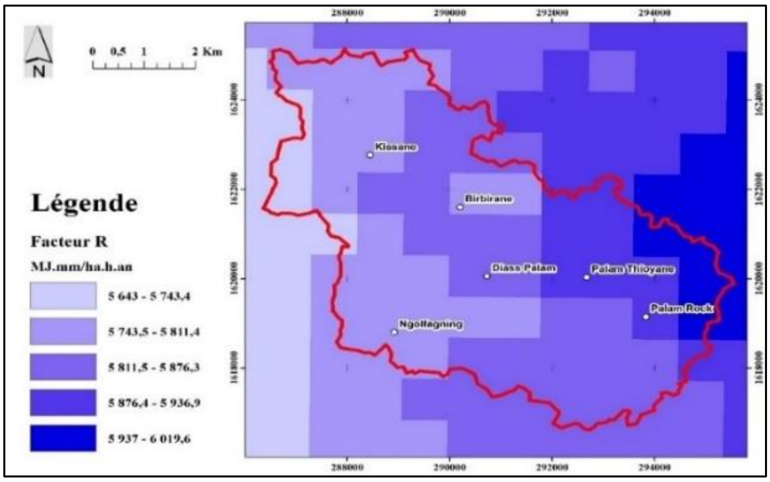

Figure 3: R factor

Climatic data analysis shows that, based on the distribution of rainfall as a function of altitude, the spatialization map of the R factor (Fig.3) shows an increasing gradation of values with topography. Thus, the erosivity of rainfall naturally increases where the slope is very steep. R values range from 5600 - 6100 MJ.mm/ha.h.an

Calculating soil erodibility (K)

In the "vector" file containing the polygons corresponding to the different soil types, the addition of a new field containing the K factor makes it possible to spatialize this factor. Conversion to a raster image was carried out using the ArcToolBox "feature to raster" conversion tool on ArcGIS. The pixel size of this raster is 10 m by 10 m. The K-factor distribution map obtained is shown in the figure below

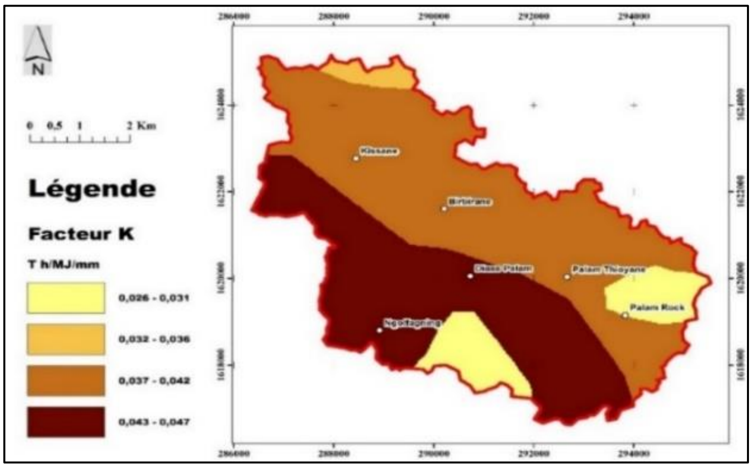

Figure 4: K factor

The map shows a heterogeneous distribution of the K factor. The village of Palam rock has a low K factor. These, composed in the majority of cases of luminous clay soils, can be sensitive to erosion. On the other hand, the villages of Kissane, Diass and Ngolfagning have high K-factor values, making them sensitive to runoff, and most of them have silty sand or ferruginous laterites.

Plant cover factor calculation

The distribution map for the C factor was obtained using the same methodology as for the K factor, i.e. by transforming vector data into a raster layer with a resolution of 10 m for the output pixels.

The most erodible parts are mainly located in bare areas, while those with dense forest-type vegetation are less susceptible to erosion.

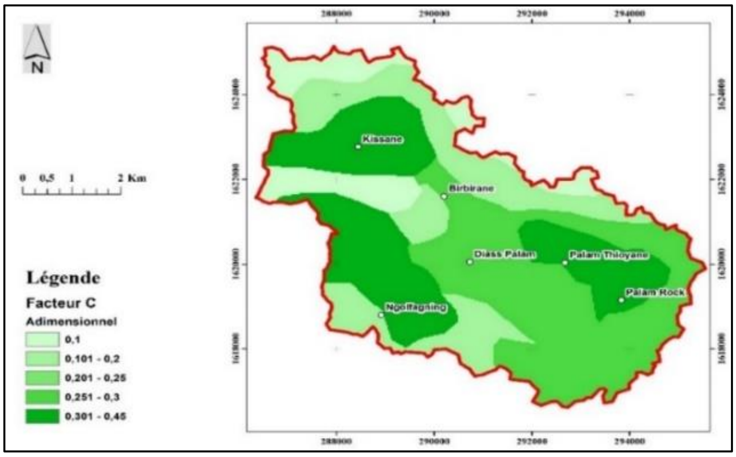

Figure 5: C factor

The distribution of the C factor is fairly heterogeneous throughout the area. Vegetation cover protects the soil and acts as a buffer for raindrops, slowing runoff and infiltration. Thus, for low vegetation, soil loss decreases with increasing plant cover.

Calculating the P factor

The erosion control factor P is defined as the ratio between the soil losses of a field on which conservation practices are applied and those of a field cultivated in the direction of the slope.

Calculation of the LS factor

This factor represents the combined effect of slope length and inclination.

- For a regular slope

Following regression analysis of erosion plot results, Smith and Wischmeier [14] established the following relationships for the "L" factor:

$$L= \left(\frac{\lambda}{22,1}\right)^{m} \text{ m} \qquad (2)$$

Avec L le facteur de longueur de la pente ;

λ With L the slope length factor;

m is the length of the slope (m);

m exponent, generally equal to 0.5.

The "S" factor is given by equation [14] below:

$$S = 0.065 + 0.045s + 0.0065s2 \qquad (3)$$

S is the slope inclination factor;

s is the slope inclination (%).

The slope length represents the distance the flow can travel from the top of the slope to an interceptor structure.

- For irregular slopes

For irregular and complex slopes, Foster and Wischmeier [15] have developed a method for estimating the LS factor. The slope is divided into several sections and the LS factor calculated for an exponent m of 0.5.

Using the relationships established by WISCHMEIER, the product L.S. can be calculated:

$$LS = (L/22,13)^{m}.(0,065 + 0,045.S + 0,065.S^{2}) \qquad (4)$$

L: length of slope (m)

m: exponent depending on several parameters, including slope
m = 0.5 when the slope < = 10
m = 0.6 for slopes > 10%.
S: slope (%)

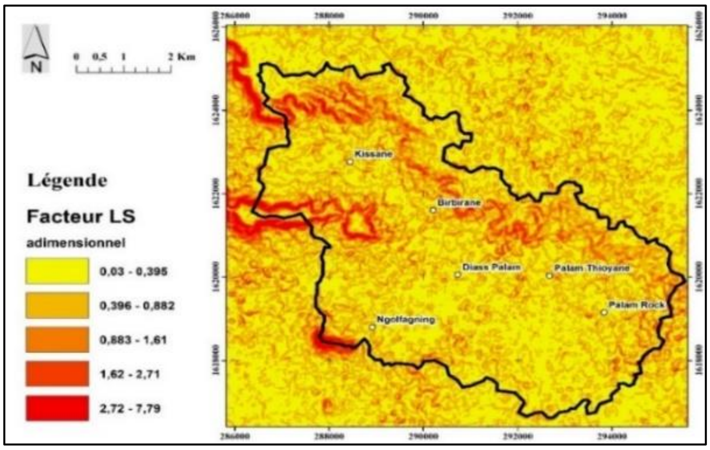

Figure 6: LS factor

Estimation of soil losses (A)

Analysis of the four main factors responsible for erosion in our study area has enabled us to quantify soil losses at catchment level.

Data are cross-referenced by multiplying the values of the four factors R, K, LS and C in the "raster calculator" of the ArcGIS Spatial Analyst module.

The result of this multiplication is a "raster" layer giving the quantity of potentially erodible land in t/ha.yr over the entire study area (table 8). To make the map easier to read, the values obtained have been grouped into classes.

Figure 7 shows the distribution of degrees of soil loss as a percentage of the study area surface.

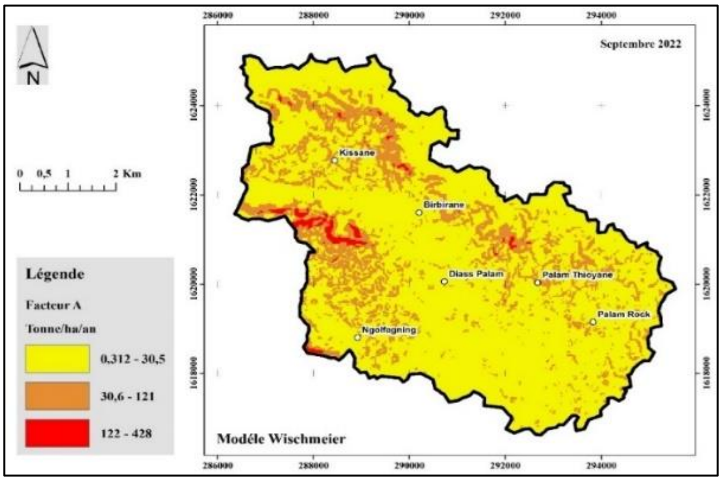

Figure 7: A factor

Table 1: Land loss

Land loss (Tonne/ha/year)	Erosion sensitivity class	Area in km^2	Area in Hectare	Percentage (%)
0.31 – 30.5	Low	34.02	3402.22	79
30.6 – 121	Medium	8.36	836.18	19
122 - 428	High	0.48	48.24	2
		42.86	4286.61	100

Analysis of the land loss map has enabled us to assess land loss in the watershed.
For areas with low water erosion, losses are estimated at 30 Tonne/ha/year, covering 79% of the watershed's surface area, i.e. 34km^2.
Medium-sensitivity zones, which account for 19% of the watershed (8km^2), are areas where the soil and slope are most conducive to water runoff towards lower points. The impact of these two factors is most visible in the surrounding villages, resulting in a loss of almost 400 Tonnes/ha/year of arable land.
The notion of spatialization of the erosion hazard therefore takes on its full meaning, since we can observe areas with low sensitivity and areas with high sensitivity to the erosive process.
The application of Wischmeier and Smith's formula, taking into account the values of the five factors, highlights the areas most vulnerable to erosion.

Conclusion

This research project, carried out using a Geographic Information System, has enabled us to quantify soil losses at catchment level. The method used, despite its limitations, provides an important aid to decision-makers in simulating scenarios for the evolution of the region and in planning interventions to combat erosion.
The results obtained show that the soils in the watershed are affected by several factors that promote erosion, namely steep slopes, low vegetation cover and soil erodibility.

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