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Research Article

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Study of Soil Vulnerability to Water Erosion in the Kissane Watershed by the Improved Bouyoucos Method

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Abstract Water erosion is one of the major environmental and agricultural problems affecting the Thiès plateau and more particularly the village of Kissane. The study of this phenomenon requires the understanding and characterization of the textural and structural components of the soil. Knowing that the relative combination of sand, silt and clay in a soil is considered to have an impact on erosion resistance, this present study relates the composition of the soil to a risk assessment index erosion "EIROM". Thus, the objectives set are first of all to determine the erosion risk assessment index, then to classify the degree of soil erodibility and finally to produce a vulnerability map of the soil erosion risks in Kissane watershed. To do this, a field campaign was carried to take soils samples from different horizons followed by treatment in the laboratory.

Bqsed on the Bouyoucos index results, we calculated the EIROM risk assessment index for each soil sample taken in the study area. After a classification of the degree of erodibility according to the 'ROM' scale, we identified three (3) classes of vulnerability to water erosion: low risk areas (53.4%), moderate risk areas (44.9%) and very high risk areas (1.7%). These results made it possible to draw up an erosion risk assessment map to guide the various possible soil conservation intervention actions.

Keywords Water erosion - Kissane - Bouyoucos index - EIROM index - Erodibility - Vulnerability

1. Introduction

Land is a non-renewable resource on a human timescale. It takes 100,000 years for a single meter of topsoil to form from rock in a temperate country, but only 25 years are enough to erode this soil to bedrock [1]. In Saharan and sub-Saharan countries, water and soil resources are scarce and very vulnerable. In addition, water erosion is a natural phenomenon of soil degradation that depends on the physical characteristics of the soil, the topography, the climate and the land use practice. However, when it concerns agricultural areas, water erosion becomes a major issue and leads upstream to a degradation and loss of soil production potential, in particular the reduction in soil thickness, the creation of gullies that hinder soil cultivation, and a drastic loss of nutrients that jeopardise the availability of arable land. Downstream, the damage can lead to flooding with all its consequences, degradation of roads and/or contamination of water resources. The impact of land degradation affects two thirds of the country's arable land and has an economic cost of 1% of GDP [2]. Today, the Thies plateau, due to its uneven relief, is an area in very advanced degradation process due to numerous natural factors such as water erosion. This uneven relief, estimated at 138 m, makes it a runoff emitting area that impacts almost the entire Thies region. In our study area, the village of Kissane (Figure 1), located in the commune of Notto, this part of the Thies plateau is under the influence of water erosion due to runoff. The general objective of our study is to quantify the degree of erodibility of soils through their textural compositions. This was done by a geotechnical approach consisting in the experimental determination of the Bouyoucos erosion based on the granulometric distribution.

2. Materials and Methods

2.1. Presentation of the study area

The study area is located in the municipality of Noto, the location and boundaries of which are shown in Figure 1.

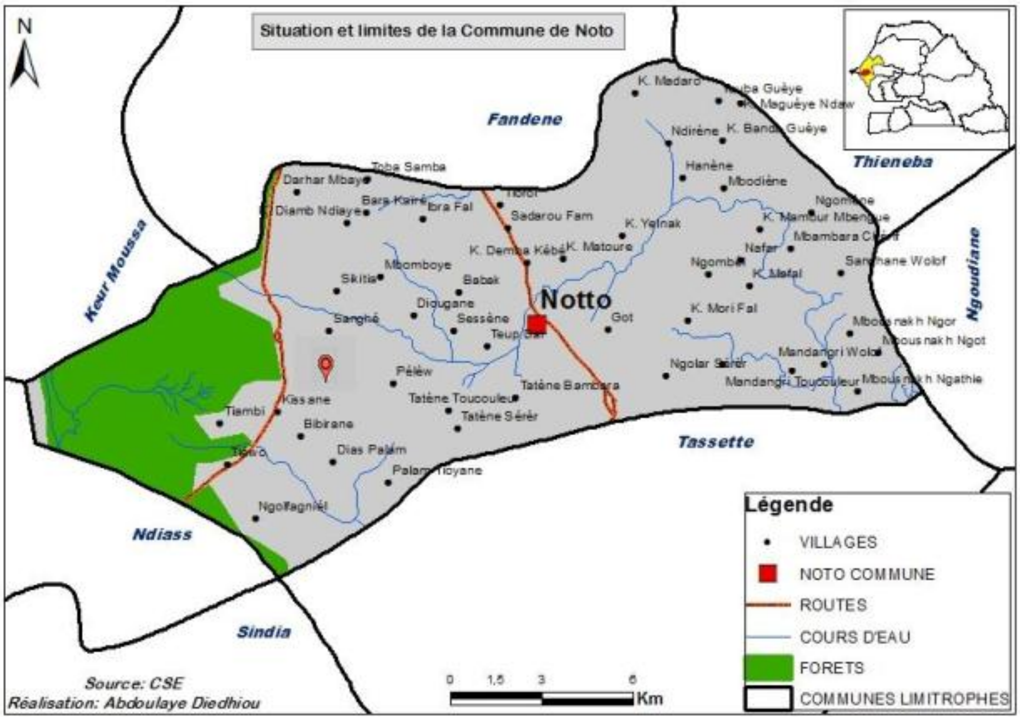

Figure 1: Location of the study area

2.2. Methodology

Field campaigns were carried out to take about fifty soil samples in the Kissane watershed.

The fifty (50) manual test pits carried out in the village of Kissane enabled samples to be taken at a depth of 40 cm for geotechnical testing. For each borehole, if the environment is stratified, two samples were taken between the level of the natural ground and twenty (20) cm, then between twenty (20) cm and forty (40) cm. On the other hand, if the soil encountered is homogeneous, only one sample is taken at forty (40) cm from the natural ground level. Then, tests by sieve analysis were carried out in the laboratory to identify the textural composition of the soils and to calculate the Bouyoucos index.

2.2.1. Grain size analysis

The grain size analysis of a soil consists of the quantitative determination of the distribution of soil particles in diameter classes **[8]**. The reference sieves for the test are 2 mm, 0.2 mm and 0.08 mm.

Table 1: Results of the particle size analysis

Sample number	**S1-2**	**S2-1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7-1**	**S8-1**	**S 8-2**	**S 9**
Horizon (cm)	20-40	0-20	0-40	0-40	0-40	0-40	0-40	0-20	0-20	20-40	0-40
% < 2 mm	99.3	95.2	100.0	99.9	99.8	99.7	36.3	62.1	97.3	94.2	99.3
% < 0.200 mm	73.0	38.0	38.0	60.0	68.0	45.0	20.0	52.0	62.0	59.0	80.0
% < 0.080 mm	40.4	13.4	28.2	19.5	22.1	9.4	8.2	25.0	21.6	18.6	63.2
LCPC classification	SL	SL	SL	SL	SL	SL	SL	SL	SA	SA	SA

Following the granulometric analysis (Table 2), a classification of the soils according to the standards of the 'Laboratoire Centrale des Ponts et Chaussées (LCPC)' was carried out to determine the nature of the soils in the study area. Indeed, the samples taken are composed of 45% clayey gravel (GA), 25% silty sand (SL), 21% clayey sand (SA), 9% very plastic clay (At).

2.2.2. Description of the Bouyoucos model

Soil erodibility is a complex phenomenon that can depend on its physical properties, which are its texture and structure. Indeed, the texture of a soil is defined as the relative proportions (in percentage) of clayey, silty and sandy particles which constitute the fine soil of the horizon and as for the structure, it is the mode of arrangement of the solid particles between them **[3]**. However, the erodibility factor of a soil can be affected by its composition of clay (particles<0.002 mm), silt (0.002-0.05 mm) or fine sand (0.05-0.2 mm) [4]. The high content of sand and silt means that the soil can be easily eroded as they are large and of low cohesion and will be easily carried away by runoff water. In order to estimate the sensitivity of a soil to erosion, the American researcher George John Bouyoucos developed in 1962 an index that allows the erodibility of a soil to be predicted through its textural composition **[5]**. Indeed, it uses the three granulometric fractions of fine soil, namely clay, silt and sand.

The Bouyoucos index IBou is expressed by the relation:

$$\boldsymbol{I_{Bou}} = \frac{\boldsymbol{\%sand+\%silt}}{\boldsymbol{\%clay}} \quad (1)$$

After an improvement of the Bouyoucos formula by Zainal Abidin and Mukri [6], a new erosion risk assessment formula (EIROM) is developed to predict the expected degree of erosion across a catchment [7] [8]. This index has been successfully applied to the study of erosion-induced landslides in Malaysia [8].

This formula is given by equation (2).

$$EI_{ROM} = \frac{\%sand+\%silt}{2(\%clay)} \quad (2)$$

With EI_{ROM} representing the Zainal erosion index. Based on equation (2), a first scale named after the researchers Roslan and Mazidah was developed to evaluate the degree of erosion of an area. The results of the classification are given in the table below.

Table 2: Degree of erodibility according to the Roslan index

ROM' scale	Degree of soil erodibility
<1.5	low
1.5–4	moderate
4 – 8	high
8 – 12	very high
>12	critical

3. Results et Discussion

3.1. Determination of the Bouyoucos Index

Water erosion is a complex phenomenon in which many factors come into play. But the erodibility of a soil depends on its nature and more particularly on its textural composition. However, the most sensitive soils are those that are predominantly sandy. The analysis of erosion by the Bouyoucos index (Table 3) revealed values ranging from 0.63 (borehole S33-2) to 19 (borehole S8-1) with an average value of 3.27 on the samples taken. The results are given in Table 3.

Table 3: Bouyoucos index

Sample N°	Horizon (cm)	Bouyoucos index	Sample N°	Horizon (cm)	Bouyoucos index
S1	0-40	3.55	S23	0-40	2.52
S2-1	0-40	4.83	S25	0-40	2.10
S2-2	20-40	1.83	S26	0-40	3.15
S3	0-40	6.69	S27-1	0-20	1.41
S4	0-40	4.82	S27-2	20-40	3.35
S5	0-40	6.14	S28	0-40	4.64

S6	0-40	2.55	S29	0-40	3.91
S7	0-40	4.55	S30	0-40	1.86
S8-1	0-20	19	S31	0-40	0.89
S8-2	20-40	1.37	S32	0-40	1.09
S9	0-40	2.17	S33-1	0-20	1.66
S10	0-40	6.58	S33-2	20-40	0.63
S11-1	0-20	3.35	S34	0-40	2.43
S11-2	20-40	5.67	S36	0-40	3.06
S12-1	0-20	5.17	S37	0-40	0.76
S13	0-40	7.24	S38	0-40	0.71
S14	0-40	1.61	S39	0-40	3.92
S15	0-40	4.23	S40	0-40	2.95
S16-1	0-20	5.24	S41	0-40	2.24
S16-2	20-40	3.83	S42	0-40	2.3
S17	0-40	5.23	S43	0-40	0.85
S18-1	0-20	3.26	S44	0-40	2.49
S18-2	20-40	2.02	S45-1	0-20	1.30
S19-1	0-20	2.40	S45-2	20-40	0.69
S19-2	20-40	1.09	S46	0-40	3.07
S20	0-40	4.66	S47	0-40	2.7
S21-1	0-20	1.95	S48	0-40	2.80
S21-2	20-40	1.63	S49	0-40	2.10
S22	0-40	2.48	S50	0-40	3.0

Based on these results, we calculated the EIROM Erosion Risk Assessment Index and the results are given in Table 4 below.

Table 4: Erosion Risk Assessment Index EIROM

Sample N°	Horizon (cm)	EIROM	Degree of erosion	Sample N°	Horizon (cm)	EIROM	Degree of erosion
S1	0-40	1.8	Moderate	S23	0-40	1.3	moderate
S2-1	0-40	2.4	Moderate	S25	0-40	1.1	moderate
S2-2	20-40	0.9	Low	S26	0-40	1.6	moderate
S3	0-40	3.3	Moderate	S27-1	0-20	0.7	low
S4	0-40	2.4	Moderate	S27-2	20-40	1.7	moderate
S5	0-40	3.1	Moderate	S28	0-40	2.3	moderate
S6	0-40	1.3	Low	S29	0-40	2.0	moderate
S7	0-40	2.3	Moderate	S30	0-40	0.9	low
S8-1	0-20	9.5	Very high	S31	0-40	0.4	low
S8-2	20-40	0.6	Low	S32	0-40	0.5	low
S9	0-40	0.7	Low	S33-1	0-20	0.8	low
S10	0-40	1.1	Low	S33-2	20-40	0.3	low
S11-1	0-20	3.3	Moderate	S34	0-40	1.2	low
S11-2	20-40	1.7	Moderate	S36	0-40	1.5	low
S12-1	0-20	2.8	Moderate	S37	0-40	0.4	low
S13	0-40	2.6	Moderate	S38	0-40	0.4	low
S14	0-40	3.6	Moderate	S39	0-40	2.0	moderate
S15	0-40	0.8	Low	S40	0-40	1.5	low
S16-1	0-20	2.1	Moderate	S41	0-40	1.1	low
S16-2	20-40	2.6	Moderate	S42	0-40	1.2	low
S17	0-40	1.9	Moderate	S43	0-40	0.4	low
S18-1	0-20	2.6	Moderate	S44	0-40	1.2	low
S18-2	20-40	1.6	Moderate	S45-1	0-20	0.7	low
S19-1	0-20	1.0	Moderate	S45-2	20-40	0.3	low
S19-2	20-40	1.2	Moderate	S46	0-40	1.5	low
S20	0-40	0.5	Low	S47	0-40	1.4	low
S21-1	0-20	2.3	Moderate	S48	0-40	1.4	low
S21-2	20-40	1.0	Low	S49	0-40	1.1	low
S22	0-40	0.8	Low	S50	0-40	1.5	low

3.2. Interpretation of results

The identification of the textural composition of the soil in the Kissane watershed allowed us to calculate the Bouyoucos and EIROM indexes. We note that according to Table 4, the erodibility index varies between 0.3 and 9.5 with an average value of 1.63. This variation in the erodibility index shows us areas of low vulnerability to erosion which represent 53.4%, areas of moderate vulnerability 44.9% and areas of very high vulnerability 1.7%. Despite this low risk of erosion in the catchment area, we note that the phenomenon remains alarming and affects a large part of the area.

Other studies on structural stability have shown that the soils in the catchment area are stable [4]. However, we can say that water erosion in Kissane is not due to structural or textural instability of the soils but rather to extrinsic factors such as the high erosivity of rainfall and runoff and also its topography.

Based on the results, a soil erodibility map is developed to spatialize the distribution of EI_{ROM} values and also to provide an overview of the areas at risk.

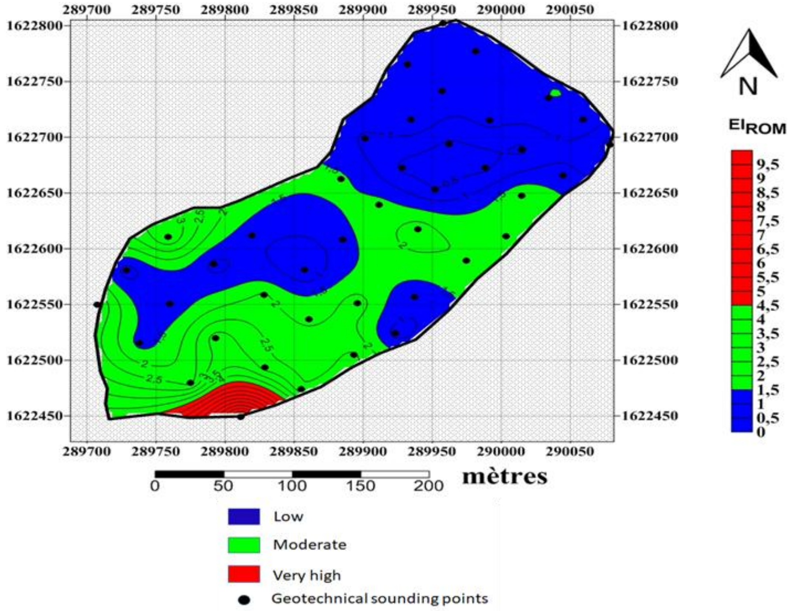

Figure 2: Soil erodibility map according to EIROM

This erodibility map (Figure 2) shows that the southern part of the catchment area has the highest soil erodibility index values. This can be explained by the topography, which has quite steep slopes going south, and the steeper they are, the more energy the water flow takes and carries away the fine soil. In order to visualize this phenomenon, we have made a 3D representation of the area (figure 3) according to the erodibility index. However, we can see that the highest values of the erodibility index are found on the slopes and the lowest on the shallows

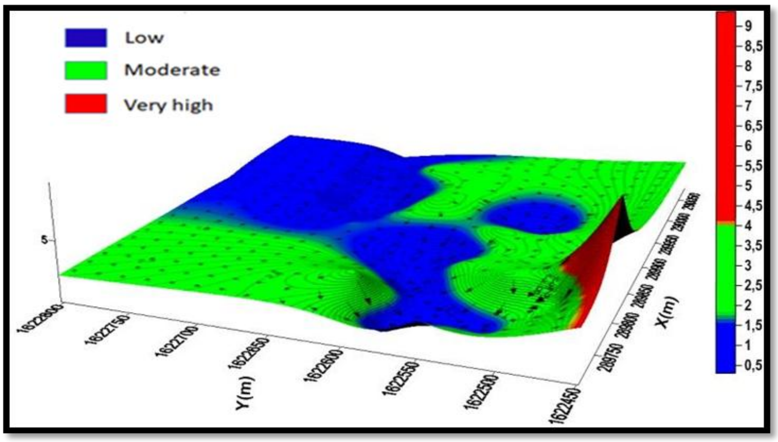

Figure 3: 3D view of the evolution of the soil erodibility index in the Kissane watershed

4. Conclusion

The use of the Bouyoucos modified method allowed us to classify the degree of soil erodibility in the area. In addition to the maps produced, we were able to observe the evolution of erosion according to the granulometric composition of the soils in the study area.

This study showed that water erosion in Kissane is not due to structural or textural instability of the soil but rather to extrinsic factors such as the high erosivity of rainfall and runoff and also its topography.

The soil erodibility map developed from the results provides a good spatial distribution of EIROM values and thus gives an overview of the areas at risk. The map is an excellent decision-making tool for planning actions in the area.

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