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Mapping of soil loss in the gourou watershed located north of the city of Abidjan in Ivory Coast

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Abstract

This study aims to characterize soil loss in the Goura watershed. To achieve this objective, the work required monthly rainfall data, satellite images, altimetry data, and cartographic data. The methodology applied to this work was based on the revised version of the Universal Soil Loss Equation (RUSLE) developed by (29). The analysis reveals that the average soil loss is 75 t/ha/year throughout the basin. This is well above the tolerable threshold for soil loss, which is an average of 20 t/ha/year. Moderately sensitive areas cover 15.203 km^2, or 55% of the entire study area. They lose up to 202.07 t/ha/year of material. This area is more localized in the northwest and southeast of the basin. The areas most sensitive to erosion in the Goura watershed cover 11.9 km^2, or 45% of the entire study area, and can lose up to 790.62 t/ha/year of material. This area is located in the southwest, center, and northeast of the basin.

Keywords: Mapping; Erosion dynamics; Goura watershed; Ivory Coast

1. Introduction

West Africa is currently facing serious environmental problems, particularly water erosion. The consequences of this phenomenon are numerous, dramatic, and costly for the economy, and are therefore a global concern ([11], [28], [30]). Indeed, water erosion causes loss of human life and the destruction and/or weakening of people's livelihoods, undermining their food and nutritional security [5]. Water erosion is a natural geophysical phenomenon that has shaped the Earth's surface over geological time ([32], [12]). It is a real destroyer of property (homes, socio-economic infrastructure). This phenomenon also affects water quality and the storage capacity of dams. In tropical cities where the soil is subjected to heavy rainfall, erosion occurs more intensely in areas where the soil is completely exposed on uneven terrain, when no protective measures are in place to slow its progress. Heavy rainfall is often the cause of disasters (landslides, rockfalls), but it is not the only factor. Indeed, the water content of the soil, the characteristics of the terrain (slopes, soil depth) and vegetation cover are also decisive factors. In the city of Abidjan, water erosion is particularly evident. Erosion is washing away open gutters, the foundations of private and public buildings, and fences at a rate of 1 to 350 cm or more [14]. The objective of this study is to estimate soil loss in the Gourou watershed. Specifically, it aims to map the factors contributing to erosion and then quantify soil loss in the Gourou watershed.

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2. Material and methods

2.1. Presentation of the Gourou watershed

The Gourou watershed is located between longitudes 4°1'40''and 3°59'10'' west and latitudes 5°21'00''and 5°24'00'' north. It covers an area of 28.8 km² (2,880 hectares), or 8.83% of the land area of the north-central district of Abidjan [30]. This basin is bordered to the west by the municipality of Attécoubé, to the east by the municipality of Cocody, to the north by the municipality of Abobo via the Banco crossroads, and to the southwest by the municipality of Adjamé [2]. (Figure 1).

The study area has a humid tropical climate with an average annual temperature of 26°C. Monthly relative humidity ranges from 80% to 90% (30). In 2017, approximately 2,060 mm of rain fell. In addition, it rains on average 100 to 133 days per year in the city of Abidjan [30]. Rainfall in Abidjan lasts for hours or even several days, weakening the soil and sanitation systems [30].

The predominant vegetation in the study area is forest, which has gradually given way to housing due to rapid urbanization in the district of Abidjan [15]. The remnant of this primary forest is Banco National Park, with banana, cassava, and coconut trees growing in some areas.

The basin has a dense hydrographic network due to regular rainfall [30]. All the waters in the basin converge at the Indénié crossroads and are drained by the Ebrié lagoon (Figure 1).

This basin is located on a plateau. The slopes vary from 5 to 53 m with an average of 13, 25 m. The soil consists of a layer of varying thicknesses of sand, clay, ferruginous sandstone clay, conglomerates, glauconitic sand, and marl covering older deposits [2]. Its population is estimated at 2,800,000 inhabitants, giving a density of 105,816 inhabitants per square kilometer ([22],[2]).

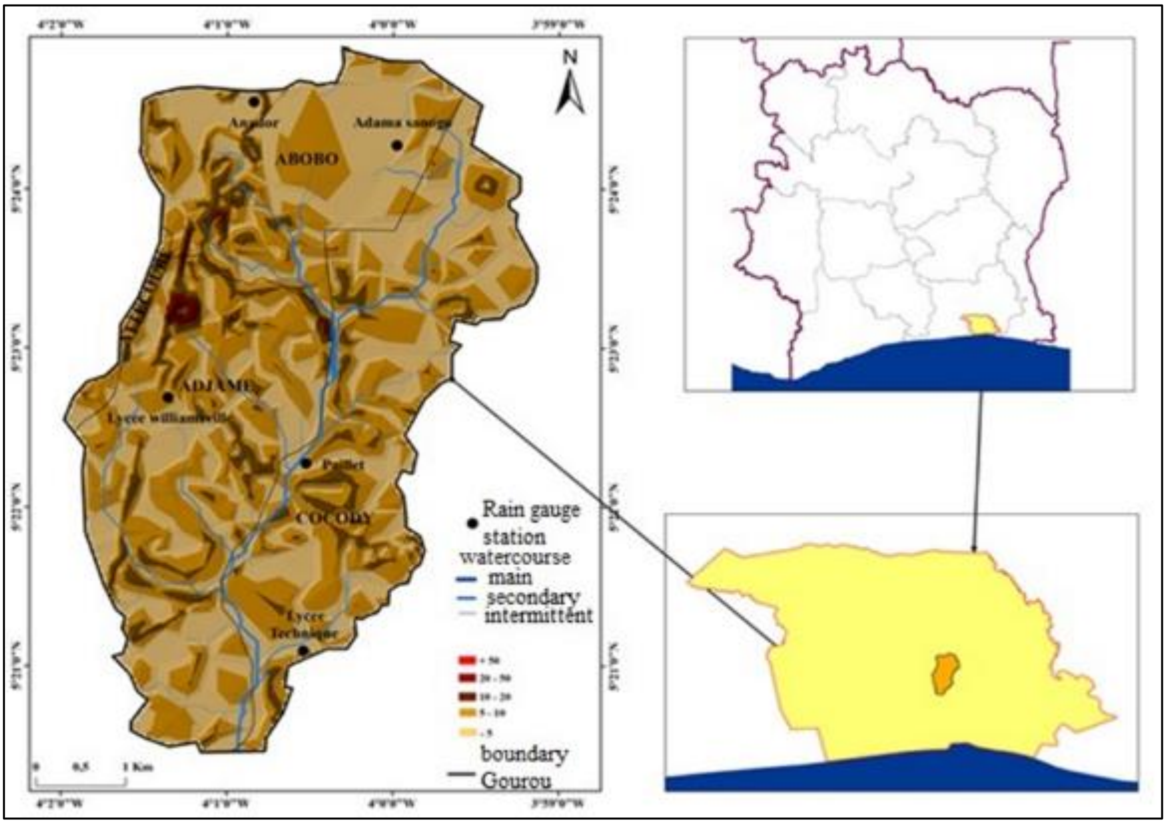

Figure 1 Geographic location of the Gourou water shed (Data source: [15] modified; Image Google Earth, 2018; CIGN, 2018)

2.2. Study data

Several types of data were used for this study. These include rainfall, satellite, altimetry, and cartographic data. Rainfall data was obtained from the Gourou Watershed Integrated Management Project Emergency Phase. It covers only one year, 2017, as the rainfall stations are recent installations. There are five rainfall stations (Figure 1). These are the Anador, Adama Sanogo, Williamsville High School, Paillet, and Technical High School rainfall stations. They were used to determine the R erosivity factor of the RUSLE (Revised Universal Soil Loss Equation) in the Gourou watershed. The georeferenced Landsat OLI satellite image (scene no. 196/056) from 2017 was used. The image was obtained free of charge by downloading it from the US government website http://earthexplorer.usgs.gov/. It was used to show the different land cover classes in the Gourou watershed. The SRTM (Shuttle Radar Topographic Mission) data used are altimetric data of the terrain surface according to a regular grid. These SRTM data provide a topographic survey of the study area. The data acquired is in WGS 1984 geographic coordinates, in an altimetric system associated with the WGS 1984 ellipsoid. This Digital Terrain Model (DTM) was collected in 2008 by the American space shuttle Endeavour. The cartographic data comes from various sources. These include the geological map of Abidjan drawn up on a scale of 1 : 200,000 and the FAO soil map produced on a scale of 1: 500,000 in 1986.

2.3. Methods

2.3.1. Mapping of water erosion factors

There are several types of water erosion factors. These are: erosivity R, topography LS, land use C, erodibility K, and anti-erosion p.

2.3.2. Erosivity R and topography LS factors

The erosion factor (R) is defined as the aggressiveness of rainfall and is expressed in MJ.mm/ha/h/year. It was calculated using the mathematical formula proposed by [24]. This is an alternative formula that only involves monthly and annual rainfall totals. It applies to a number of stations located near the study area. To do this, we calculated the sum of the monthly rainfall totals squared divided by the annual rainfall total.

The topographic factor LS represents the combination of the effects of length L and gradient ([23],[27]). It assesses soil loss due to water erosion. Thus, the LS factor can be defined as the relationship between soil lost in an area with a slope P and length L in the corresponding standard plot of 22.1 m ([17],[8],[28]). The DTM was used as the basis for calculating the topographic factor (LS) [21] in Argis 10.5 software. The adapted equations have recently been used by [6],[17] and [9].

2.3.3. Erodibility factor K and land use C

Erodibility K is the ability of soil to resist water erosion and is expressed in t.h/ha/MJ/mm. The erodibility factor K in the Gourou basin was determined from the soil variation table in K in accordance with that proposed by [25] as used by [6] and [18].

The C factor (vegetation cover) is defined as the ratio between losses in bare soil under specific conditions and losses in soil corresponding to soil under cultivation ([29], [7]). Its value ranges from zero [3] for completely protected soil to one [1] for bare soil [21] (Table 1). It is therefore a fonctions of land use. A column has been added to the attribute table of the land use map and coded according to the type of land use as described by ([6], [31]).

Table 1 Floor area ratio C

Land use type	Factor c
Bare soil	1
Degraded forest	0.7
Degraded grassland savanna	0.6
Crop mosaic	0,5
Wooded savanna and shrubland	0,3
Mangrove	0,28

Built-up area	0,2
Reforested area	0,18
Rice field	0,15
Thick forest	0,001
Body of water	0

(Source: [16])

2.3.4. Anti-erosion factor P

P valus range from 0 for completely covered soil to 1 for completely bare soil ([24], [12], [21], [6]). The determination of the anti-erosion factor P is based on the method proposed by [17] and [31].

2.4. Estimation of soil loss

Soil loss caused by water erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE) model developed by [29]. The equation is as follows:

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

Where A = Soil loss rate in (t/ha/year), R = Rainfall erosivity in (MJ.mm/ha.h), K = Soil erodibility in (t. h/MJ.mm), LS = Slope length and inclination (unitless), C = Vegetation cover factor (unitless), P = Factor taking into account anti-erosion practices (unitless).

The methodologies summary of soil loss estimation is shown in Figure 2.

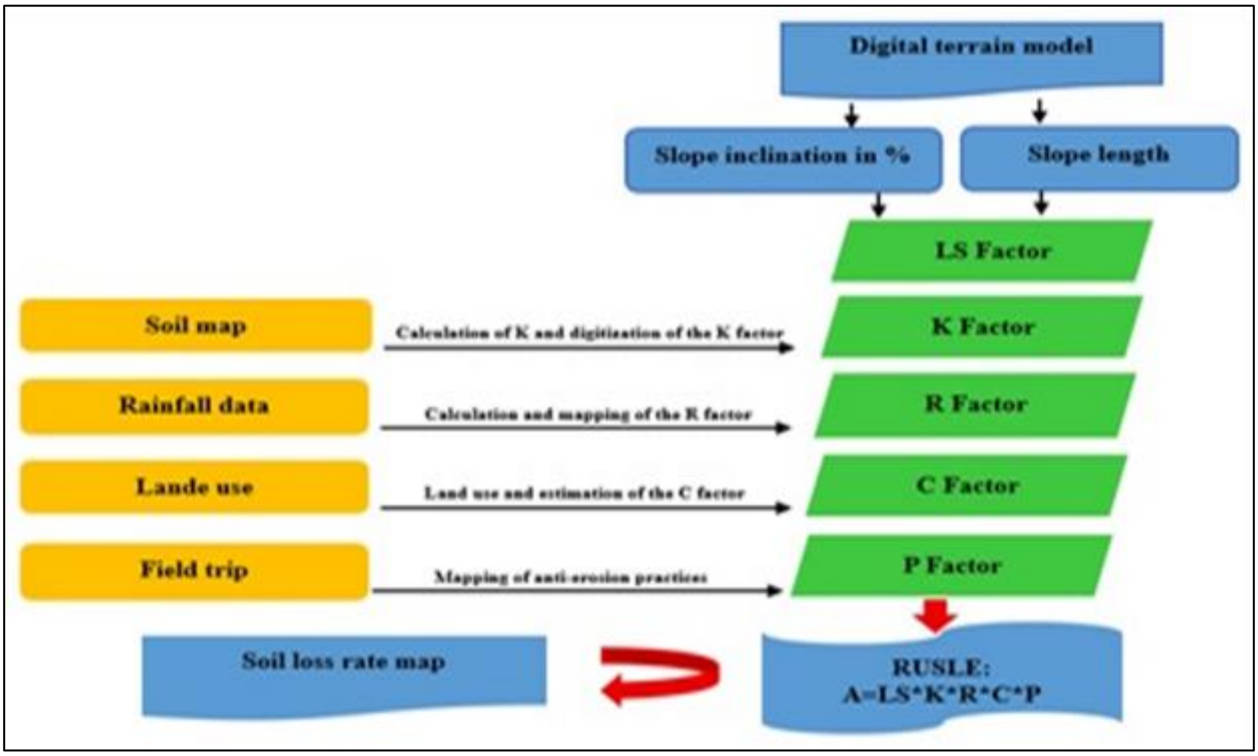

Figure 2 Modeling of water erosion using the RUSLE model

3. Results

3.1. Mapping of water erosion factors

3.1.1. Erodibility factors R and topographic LS

The erosivity factor (R) is estimated at an average of 352.86 MJ.mm/ha.h.year. Rainfall erosivity is unevenly distributed. The rainfall erosivity factor is higher in the central-eastern, northeastern, and southern parts of the basin, covering more than 72% of the entire study area. In the west, it is low and covers only 28% (Figure 3).

LS values range from 0.4 to 12.99 (Figure 4). The average index for the entire watershed is 2.94. Thus, the Gourou watershed is relatively flat. The average slope is estimated at 13.35% and the maximum slope length at 53 m. However, there is a contrast between the different geomorphological models of the Gourou watershed. In fact, the gentle slopes covering nearly 70% of the entire study area are not very sensitive to erosion processes. Conversely, the irregularly distributed steep slopes covering nearly 30% of the entire study area are more sensitive to erosion processes.

3.1.2. Erodibility factors K and land use C

The value of factor K varies between 0.07 and 0.11 t. ha.h/MJ.mm across the entire basin. The most erodible soils are sandy and clayey schist, marl and sandstone soils covering more than 70% of the watershed, with K values between 0.10 and 0.11 t.h/ha/MJ/mm (Figure 5). The low K values, mainly in the south, are 0.070-0.10 th/ha/MJ/mm and cover less than 30% of the basin, corresponding to fluvial-lagoon soils.

The value of the land cover factor C ranges from 0.001, corresponding to vegetation areas, to 1 for residential areas and bare soil in the basin (Figure 6). The largest area is the one with a C value of 0.7, corresponding to a mosaic of land cover. In this part of the study area, there is a predominance of habitat/bare ground at the expense of vegetation cover.

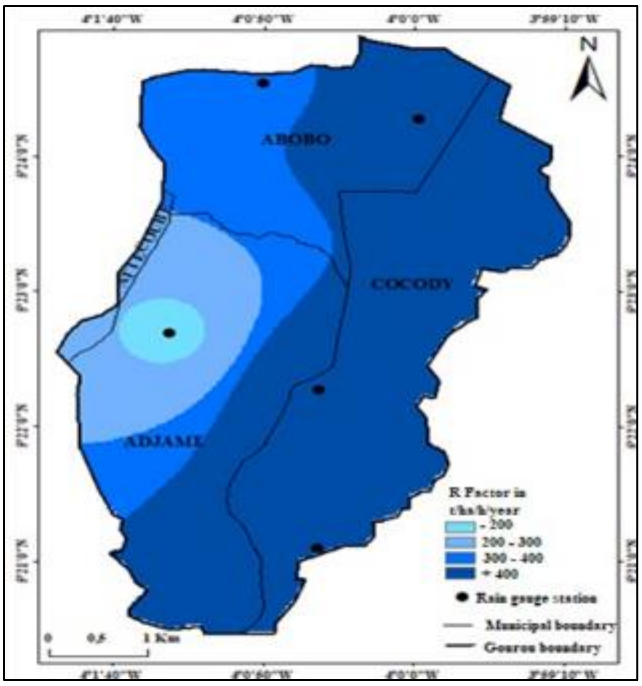

Figure 3 Erosivity R of the Goura basin (Data source: DGIBVG, 2018)

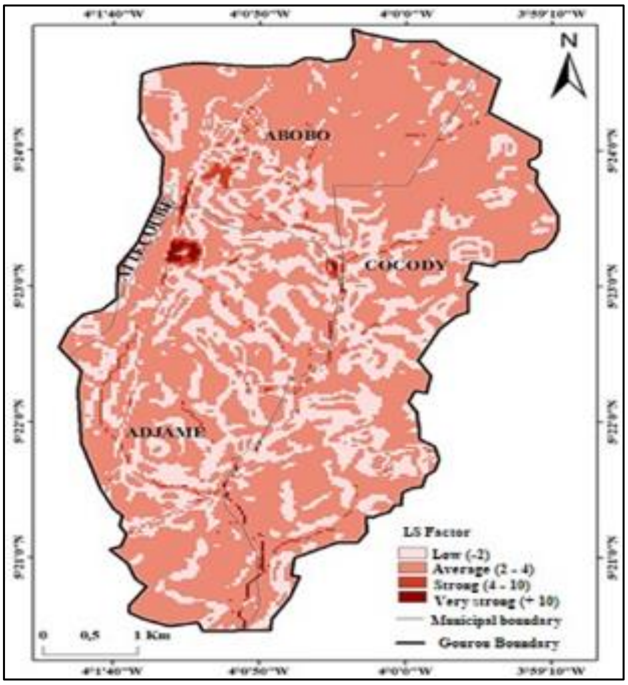

Figure 4 LS factor of the Gourou basin (Data source: MNT, 2014)

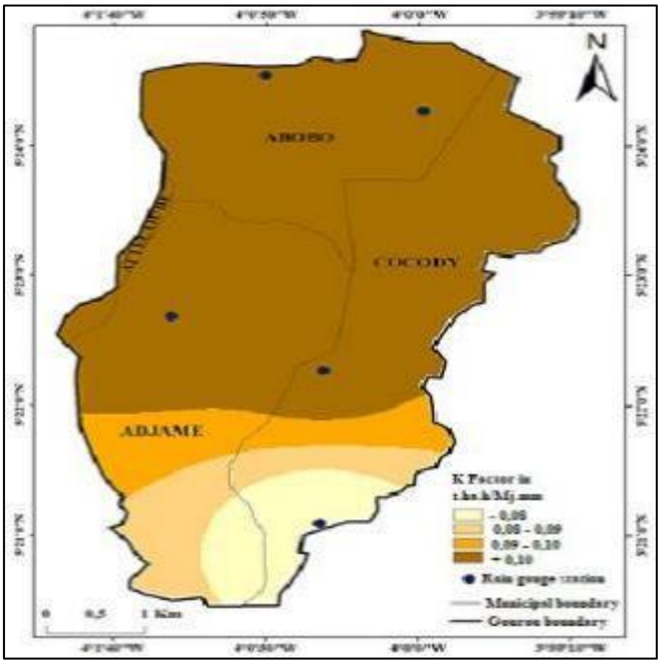

Figure 5 Erodibility K of the Goura basin (Data source: FAO, 1986)

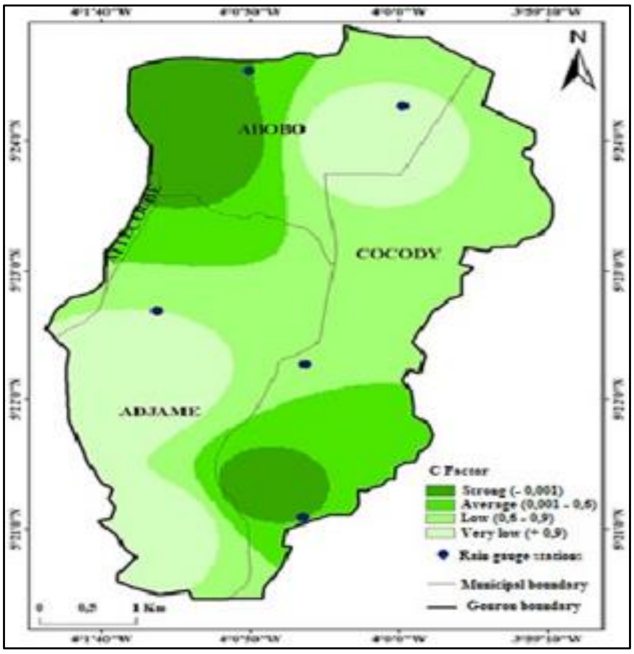

Figure 6 Soil cover C of the Gourou basin (Data source: 21)

3.1.3. Deducted factors P

The anti-erosion factor P shows the importance of soil conservation practices. The P factor indices range from 1 to 0, reflecting strip farming practices in the basin (Figure 7). In this basin, the only soil conservation practice in place is grass cultivation. Low indices are observed in the south and range between 1 and 0.75. The further north we go, the lower the factor value becomes, reaching 0, which corresponds to bare soil. This situation can be explained not only by the steeper slopes in this part of the basin, but also by unregulated land use, which degrades the vegetation cover.

Figure 7 Anti-erosion factor P for the Gourou basin (Data source: MNT, 2014)

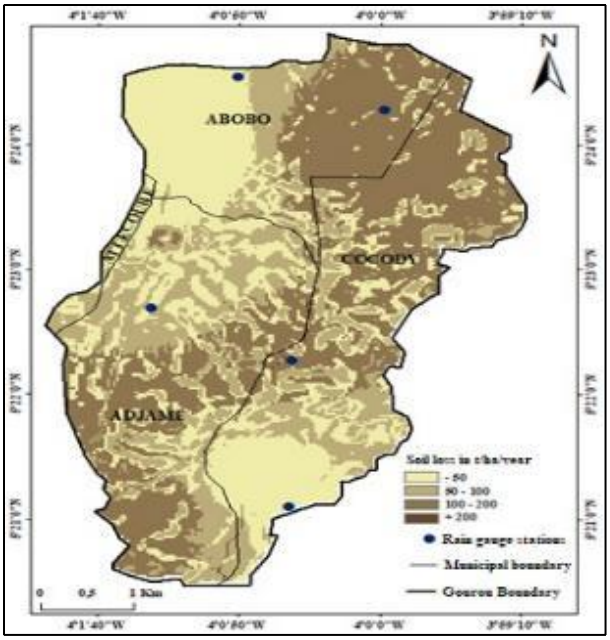

Figure 8 Soil loss in the Gourou basin (Data source: MNT, 2014)

3.1.4. Estimating losses on the ground

The RUSLE model was used to model water erosion in the Gourou watershed. The model was used to map soil loss (Figure 8). This map shows that soil loss in the watershed ranges from 2.76 to 283.22 t/ha/year. The average soil loss is therefore 75.92 t/ha/year. The area's most susceptible to erosion in the Gourou watershed cover 11.9 km², or 45% of the entire study area. This area is located in the southwest, center, and northeast of the watershed. In addition, it is an area with average rainfall, low to moderate slopes, virtually no vegetation, and soil that is highly vulnerable to rain and runoff. Moderately sensitive areas cover 15.203 km², or 55% of the entire study area (Figure 8). This area is more localized in the northwest and southeast of the basin. It is also characterized by relatively low rainfall. It has a high rate of vegetation cover with low slopes. The soil is all the more vulnerable to the phenomenon as the area has a high rate of erosion.

4. Discussions

In the Gourou watershed, the calculated erosion rate (R) varies between 178,01 MJ.mm/ha.h.year in the north and 474,98 MJ.mm/ha.h.year in the south. These results are higher than those obtained by [4] in their work on the Aghien lagoon, with values ranging from 152 MJ.mm/ha.h.year to 207 MJ.mm/ha.h.year. However, they are lower than those obtained by [6], who recorded values in the order of 600 MJ.mm/ha.h.year and [20], who observed values in the order of 1000 MJ.mm/ha.h.year.

The average erodibility value (K) for the entire Gourou basin is 0,09 t. ha/MJ/mm. This result is higher than that of [17], who notes a value of 0,025 MJ.mm/ha.h.year. However, it is lower than those obtained by [12] and [6], who observed values of 0,13 and 0,145 MJ.mm/ha.h.year, respectively. The low erodibility value obtained in the Gourou watershed reflects the high susceptibility (vulnerability) of soils to water erosion and their high permeability. In addition, soils in southern Côte d'Ivoire are generally ferralitic [20]. This condition would favor the significant leaching observed in these regions.

The calculated topographic factor (LS) indicates an average value of (4,3). This result is higher than those obtained by ([17], [12], [6]), who report values of (3,3) in the Bia watershed, (0,2) in the Mé watershed, and (0,164) in the Lobo watershed, respectively. This shows that the Gourou watershed is more rugged than the aforementioned watersheds. LS values below 5 characterize regions with generally gentle topography.

The value of the vegetation cover factor (C) is equal to 0,55. Approximately 80,02% of the basin's surface area is dominated by the class: Habitat/bare soil. This result is consistent with that of [13]. in the Gourou watershed, where he notes that more than 80% of the basin is dominated by the habitat/soil class. However, it disagrees with those of [17], with 34,32% for a C factor equal to 0,35. It should be noted that the absence of vegetation accelerates water erosion because vegetation plays a protective rôle for the soil [12].

The anti-erosion practice characterized by the P factor is considered homogeneous and reduced to unity. Moreover, several authors, such as [26] and [19], have pointed out that the USLE model was originally developed for assessing sheet and rill erosion at the local level. Therefore, its application at the regional level requires some modifications, particularly with regard to the consideration of the P factor, which is assessed on a more local basis [12].

The average soil loss of 75,92 t/ha/year obtained in the Gourou watershed is significantly higher than that obtained in several other watersheds in Côte d'Ivoire. Indeed, studies by [12], [21] and [6] show 16 t/ha/year on the Bia, 16 t/ha/year on the Mé, 24 t/ha/year in Sassandra, 30,59 t/ha/year on the Lobo, and 20 t/ha/year on the N'Zi, respectively. However, the average tolerable erosion rate limit according to RUSLE is 20 t/ha/year [10]. This means that the Gourou watershed is more erosive than the aforementioned watersheds despite its narrowness. In addition, the most sensitive areas cover 11,9 km2, or 45% of the entire study area.

These results disagree with those obtained by [12] who found a sensitive area of 29 km2 yielding up to 604 t/ha/year of material, and those of [16], who found a surface area of 189,41 km2 with losses of up to 1631 t/ha/year. On the scale of the Gourou watershed, 1,429,685.12 tons of soil per year could potentially be eroded, compared to 29,43 million and 15 million tons according to studies conducted by [17] on the Bia basin [12] on the Mé watershed. These 1,429,685.12 tons of soil removed each year contribute to the dynamics of current sediment flow, as confirmed by studies by [3] on the Gourou watershed. In the Gourou watershed, water erosion is a significant phenomenon due to the estimated soil loss rate of more than one million tons.

This could cause considerable damage, particularly economic damage and loss of life, according to studies by [1] on natural hazards in the city of Abidjan. All these studies based their modeling on the revised equation of [29]. This reflects the widespread use of RUSLE in modeling water erosion in watersheds in Côte d'Ivoire. However, some criticism of RUSLE is warranted. Indeed, RUSLE does not take into account the processes of material transport/sedimentation, which are mainly dependent on the capacity of watercourses. This estimate does not in any way predict the amount of material entering watercourses. However, it does provide information on the quantity of material potentially supplied by the watershed and thus reveals its current alteration and fragility in the face of water erosion processes.

5. Conclusion

The average soil loss is 75,92 t/ha/year, or an estimated 1,429,685.12 tons per year across the entire basin. This is well above the tolerable threshold for soil loss, which is an average of 20 t/ha/year. The average sensitive areas cover 15,203 km^2, or 55% of the entire study area. This area is more localized in the northwest and southeast of the Gourou watershed. The area's most sensitive to erosion in the Gourou watershed cover 11,9 km^2, or 45% of the entire study area. This area is located in the southwest, center, and northeast of the Gourou watershed.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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