International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 28 No. 2 Jan. 2020, pp. 458-467

http://www.ijias.issr-journals.org/

Contribution of a Geographical Information System to the study of soil erosion by water in the watershed of the hydro-agricultural dam of Babadou (Côte d'Ivoire)

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ABSTRACT: Soil erosion by water is soil loss due to water pulling and transporting the soil to a deposition site. This is the major cause of soil degradation and siltation of hydro systems. Knowledge of this phenomenon is therefore essential for better management of dam water resources. The site of the study is the watershed of the hydro-agricultural dam of Babadou. It is a small agricultural catchment area of 1630 ha in the center-west of Côte d'Ivoire. The objective of this work is to highlight the erosion by water risks and sediment transport. Thus, the Universal Soil Loss Equation (USLE) was not only used to model the factors involved in the erosion process, but also for the calculation of soil losses through a Geographic Information System (GIS). The results show an average soil loss of 6.9 t/ha/year, which represents a soil loss of 11247 t/year in the Babadou dam watershed. In addition, the soil loss map, carried out, highlights the area's most sensitive to erosion with soil losses reaching 767.4 t/ha/year. They are generally at the regions of bare soils and areas of annual crops. The sustainability of the water resource of the hydro-agricultural dam at Babadou requires the correction of vegetation cover and the use of anti-erosion practices in these areas, with a view to reducing soil loss and sediment flow.

KEYWORDS: Water erosion, USLE, Babadou, GIS.

1 INTRODUCTION

Soil erosion by water is a major cause of soil degradation, silting, siltation and eutrophication of hydro systems. It is the loss of soil due to water that tears and transports the soils to a place of deposit. Globally, it causes an annual loss of land estimated at 25 billion tonnes. This natural phenomenon, exacerbated by human activities ([1], [2]), has disturbing consequences in many countries of the world. Indeed, water erosion of soils generates environmental problems including the reduction of their storage capacity by silting and siltation and thus the alteration of physicochemical and ecological quality and eutrophication.

As part of the sustainability of the water supply for agriculture, many water reservoirs have been made in Côte d'Ivoire. Most of these reservoirs suffer from silting and eutrophication. Also, there is very little study to understand this phenomenon in the context of Côte d'Ivoire. The lack of study leaves out the silting and eutrophication problems of these reservoirs. Moreover, the studies carried out are limited to the estimation of soil losses and do not sufficiently take into account the sedimentary flow in hydro systems. This does not allow to appreciate the rate of these reservoirs silting and eutrophication. Hence the need for this study to analyze the factors of soil erosion by water in the Babadou River watershed.

2 PRESENTATION OF BABADOU WATERSHED

The study area is a small agricultural catchment area of 1630 ha (Figure 1). This is the Babadou River watershed located in west-central Côte d'Ivoire between 6°44'6.74'' and 6°42'29.62'' North latitudes and 6°27'54.83'' and 6°29'18.55'' Westlongitudes. A hydro-agricultural dam, called Babadou dam, was built in 2017 on this watershed. This dam with a capacity of 1.57 million m^3 and an area of 63.18 ha is designed for the irrigation of agricultural plots just downstream.The topography of the watershed is very low contrast with altitudes ranging from 214 to 285 m (Figure 1).

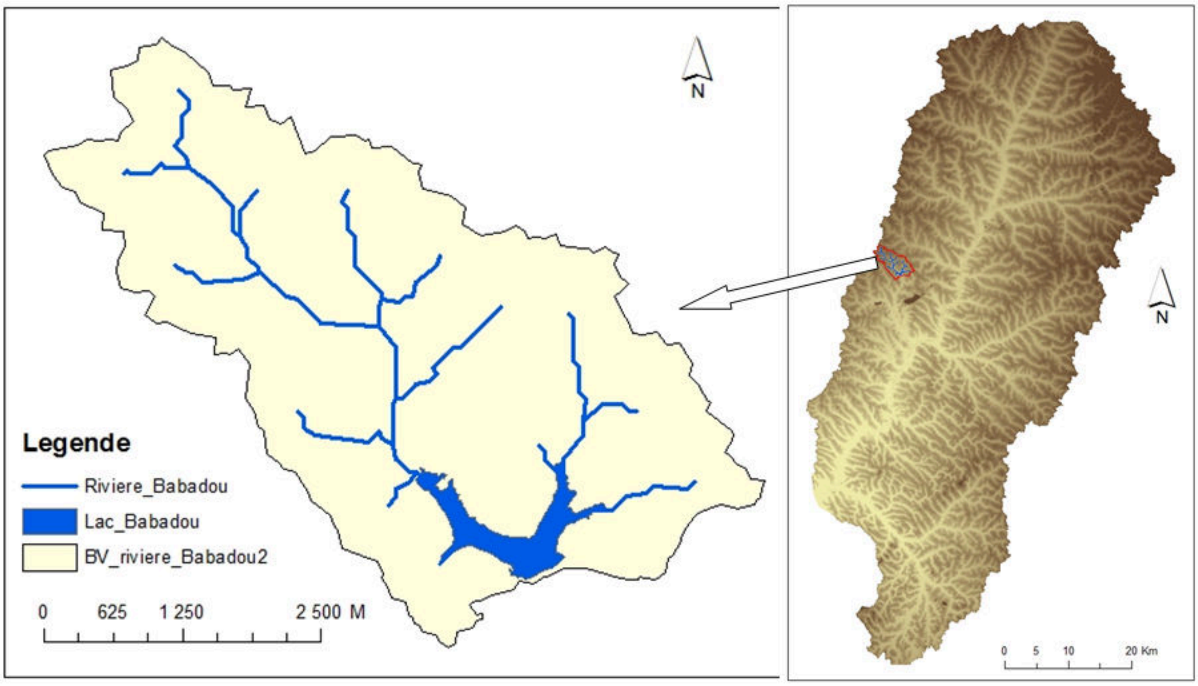

Fig. 1. Study area

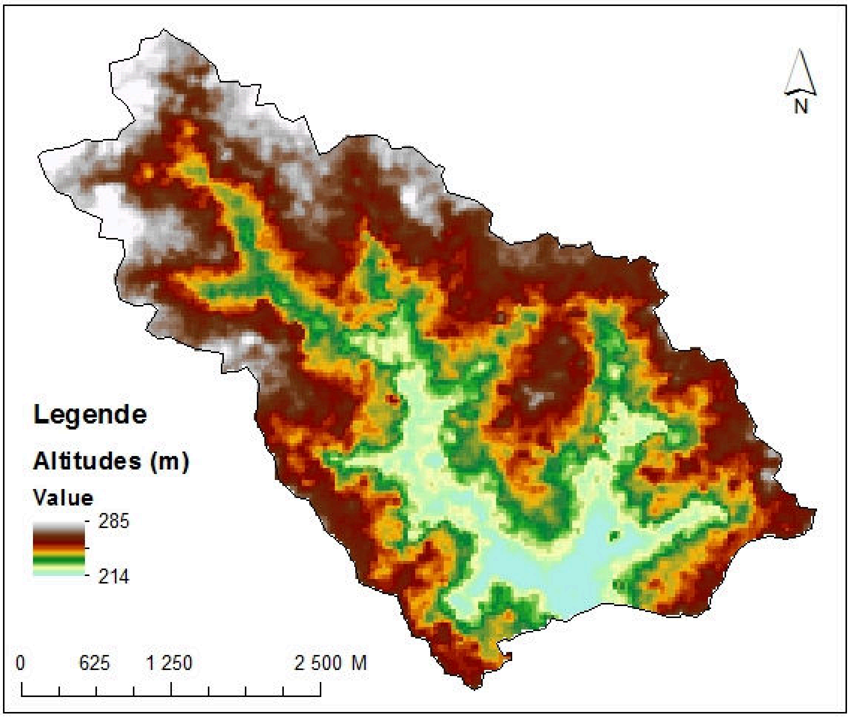

Fig. 2. Altitudes

3 MATERIAL ET METHOD

3.1 MATERIAL

REMOTE SENSING DATA

A Sentinel-2 image of the Multi Spectral Instrument (MSI) sensor (table 1) has been used for the study of land cover and for the C factor calculation. These data are available from ESA website: https://scihub.copernicus.eu/.

Table 1. Sentinel-2image Caracteristics

Bande	Multi-Spectral
Resolution spatiale	10m; 20m; 60m
Swath width	290 km
Dates	2017: December, 24
Source	https://scihub.copernicus.eu/

SOIL DATA

Most of the pedological data come from the FAO database. They present a description of the soils which makes it possible to obtain information on various parameters. For this study, the elements used are: percentages of organic matter, sand, silt and clays as well as the structure, texture and soilpermeability. They were used for the K factor calculation.

RAINFALL DATA

Rainfall data are from nine (9) weather stations located near the study area. These stations, respectively center west and south-west of Côte d'Ivoire, were chosen because they have long series (at least 30 years of observations) and have a limited number of missing and erroneous values. The data cover the period from 1950 to 2000. They were used for the R factor calculation.

TOPOGRAPHIC DATA

The Digital Elevation Model (DEM) used is 30 m resolution and is available at the following site: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp.It is used for the description of geomorphological parameters such as slope and topographic LS factor.

3.2 METHODS

There are many approaches to study soil moisture erosion. The methodological approach used for this study is based on the universal soil loss equation (USLE). This equation groups all the variables under five major factors ([3], [4]) :

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad (1)$$

Where,

A = rate of loss in soil (t/ha/year),
R = erosivity of the rain (MJ.mm/ha.h.year),
K = soil erodibility (t.ha.h/ha.MJ.mm),
LS = topographic factor integrating slope and slope length (dimensionless),
C = soil protection factor by vegetation cover (dimensionless),
P = factor expressing soil protection by agricultural practices (dimensionless).

3.2.1 R FACTOR

The rainfallerosivity (R Factor) provides information on climatic aggressiveness. There are several equations for the calculation of rainfall erosivity. In West Africa, the most commonly used equation is that developed by **[5]**. This equation establishes a relationship between the annual rainfall erosivityaverage over a sufficiently long period (20 to 50 years) and the rainfall annual average during the same period. It is expressed as follows:

$$R = a * H \quad (2)$$

With:

R: Average annual rainfall erosion expressed in MJ.mm/ha.h.year,

H: Average annual rainfall amount in mm

a: is a coefficient that takes the value of 0.5 in the study area.

Rainfall erosivity was calculated from rainfall data recorded by 9 weather stations located near the Babadou River watershed. An interpolation of the rainfallerosivity map was then done to have the spatial distribution of erosivity in the catchment area.

1.1.1. **K Factor**

The erodibility of a soil is reflected in the resistance inherent in the detachment and transport of particles by water. It is a function of the texture, the soil content of organic matter, the structure and the permeability of the soil. It was calculated using the following formula [3]:

K = 2.1x M1.14 x10-6 (12-MO) + 0.0325 x (b-2) + 0.025 x (c-3)

With:

M = (% fine sand +% silt) * (100 -% clay)
MO = Organic matter
b = Soil structure index
c = Soilpermeability

3.2.2 LS FACTOR

The LS factor is the topographic factor that combines both slope length and slope inclination. There are several equations for calculating the LS factor. For this study, we used the equation of [6], which depends on the slope, flow direction and accumulation. She expresses herself follows:

LS = [(FA * RS) /22.1] 0.4 * [(sin (S * 0.01745) /0.0896] 1.4 * 1.4

Or

FA: flow accumulation grid,
RS: Resolution of the DEM model (30m),
S: Gradient grid in degree.

3.2.3 C FACTOR

C Factor plays an important role in soil protection against erosion by water by reducing the splash effect and runoff. It is directly related to the different types of land use. The study therefore consisted in making a complete inventory of both natural and anthropogenic components of the landscape. A Sentinel-2 satellite image was used for this purpose. It allowed for a supervised classification to establish the watershed land use map.

To determine the value of the C factor corresponding to each type of land use, we have relied on the work of authors such as [3] and [5], who estimated the value of factor C for each type of land use (Table 2). The values of the factor C vary between 0 and 1.

Table 2. Value of C factor depending on the type of land use

Type of land use	C Factor
Bare soil	**1**
Degraded forest	**0,7**
Savannah with trees and shrubs	**0,3**
Degraded Grass Savannah	**0,6**
Mosaic of culture	**0,5**
Mangrove	**0,28**
Habitats	**0,2**
Wooded area	**0,18**
Paddy field	**0,15**
Dense forest	**0,001**
Water bodies	**0**

3.2.4 P FACTOR

The factor P expresses the influence of conservation methods on erosion. It takes into account soil conservation practices and cultural techniques implemented to reduce runoff and erosion. Contouring, alternating strip or terracing, reforestation in banquettes, ridging and ridging are the most effective soil conservation practices.

The factor can be taken over from the 0. The value 1 is attributed to the grounds on which no anti erosive practice is used.

3.2.5 SOIL LOSS ESTIMATION

GIS are commonly used for determining soil loss ([1], [2], [7], [8]). In this study, a GIS integrating the various factors involved in the process of soil erosion has been used for assessment and mapping of erosion rate at the watershed scale. Each factor is represented in the GIS by a layer representing the estimated values at the level of each watershed surface element (pixel). The overlay of the different gridsdata in the GIS makes it possible to have the value of the erosion rate at the level of each surface element of the watershed.

4 RESULTS

4.1 R FACTOR

Figure 3 shows the spatial distribution of rainfall erosivity in the watershed. It varies very little, with values ranging from 668.7 MJ.mm/ha.h.year South to 672.0 MJ.mm/ha.h.an North. The average value of the erosivity of the rains is 670.44 MJ.mm/ha.h.year. This shows an aggressive rain more important.

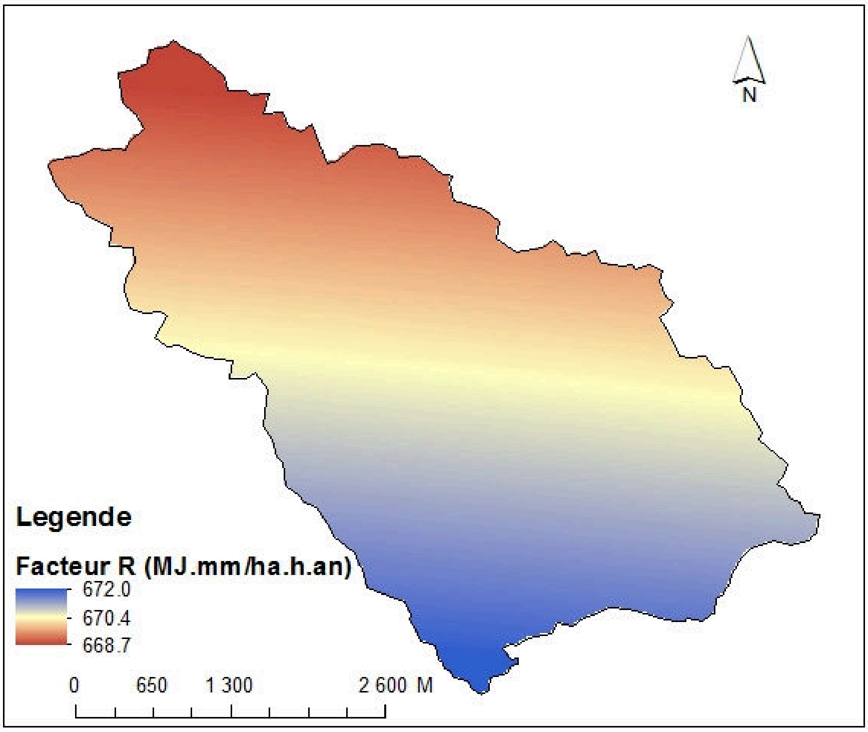

Fig. 3. R Factor

4.2 K FACTOR AND P FACTOR

The erodibility on the study area is constant with a value of 0.019 T.ha.h / ha.MJ.mm. Soils are relatively insensitive to water erosion.

Otherwise, although the Babadou River watershed is an agricultural watershed, there are no erosion control practices. The value of the factor P is equal to 1 over the entire study area.

4.3 LS FACTOR

The LS factor varies from 0 to 88 (Figure 4). Which corresponds to a relatively flat topography. The average value of LS is 1.38 which shows that the topography is relatively flat. The relief reveals a less important sensitivity to erosive watershed processes.

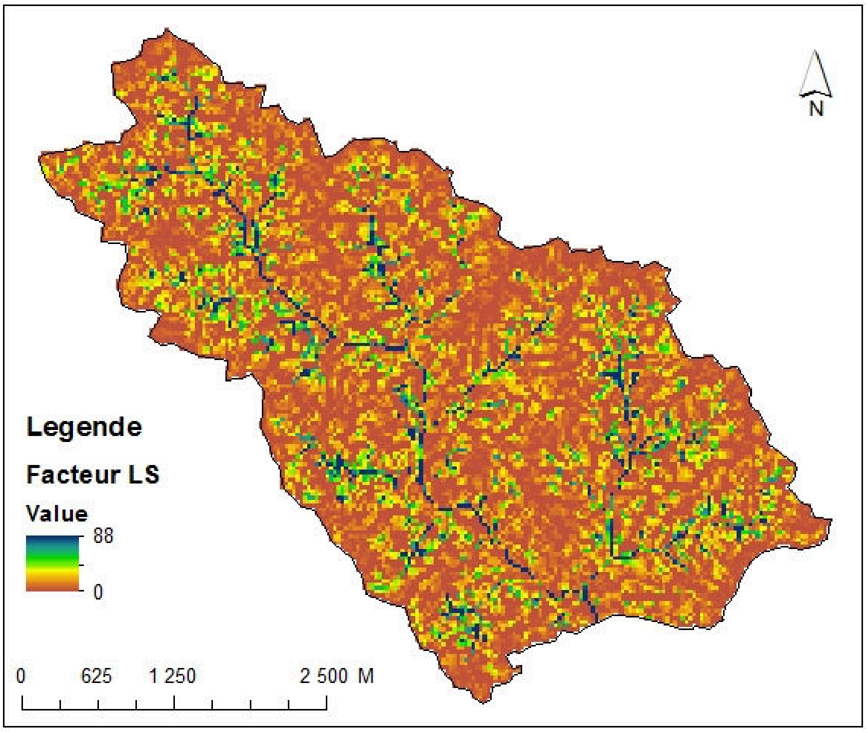

Fig. 4. LS Factor

4.4 C FACTOR

C Factor is related to land use and ranges from 0 to 1 with an average of 0.39. The different types of land cover in the study area (Figure 5) are habitats, bare soils, water bodies and vegetation cover mainly composed of degraded forests, fallow, perennial crops (plantations Hevea, cocoa, cashew nut ...) and annual crops.

The results show that the Babadou River watershed is an agricultural watershed. Crops occupy 1202 ha or 74% of the watershed. Tree crops (perennial crops) such as coffee, cocoa, palm or rubber provide good soil cover. Perennial crops are similar to reforested forests, characterized by a canopy. They protect the soil sufficiently against the impact of raindrops and runoff. These zones are associated with a lower coefficient than those occupied by more or less annual crops such as maize, peanuts, okra, tomatoes and cassava. The type of vegetation cover, consisting of annual crops, is the most sensitive to erosion processes. The highest coefficients (1) correspond to bare soils and.

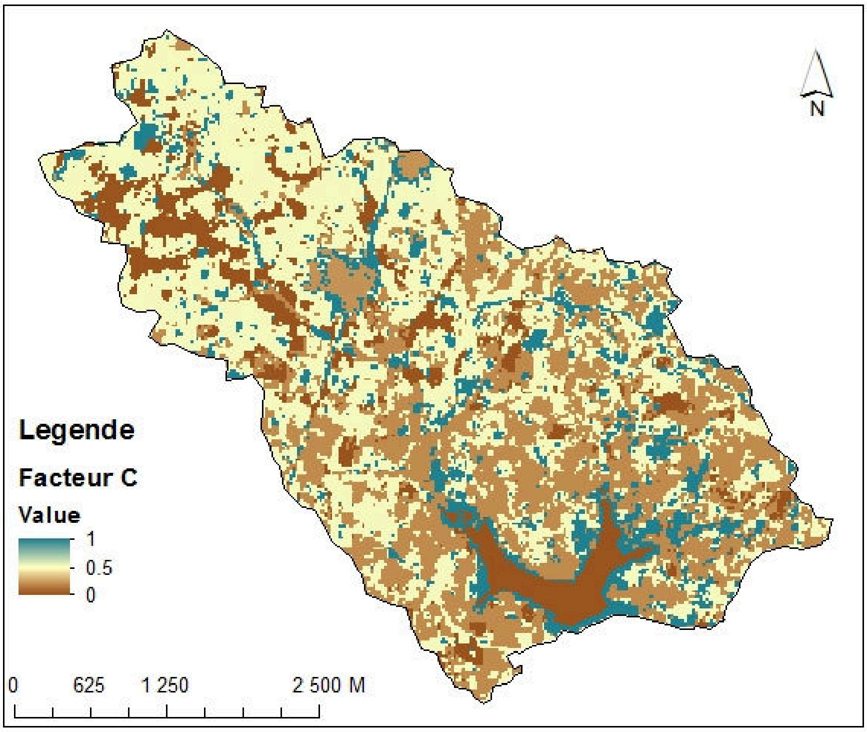

Fig. 5. C Factor

4.5 Soil loss estimation

With the help of a GIS, the various factors involved in soil erosion by water have been crossed. This made it possible to estimate soil losses in the Babadou River watershed (Figure 6). The soil loss map shows several critical points in the watershed with soil losses of up to 767.4 t/ha/year.

Soil losses range from 0 to 767.4 t/ha/year. Soil losses due to water erosion are estimated at 6.9t/ha/year, on average at the Babadou River watershed scale. This corresponds to a total annual soil loss of 11 247 t/year in the Babadou River watershed.

Soil losses are higher in annual crop plots due to the presence of low cover crops (maize, etc.) in June and July, where rains are generally more erosive.

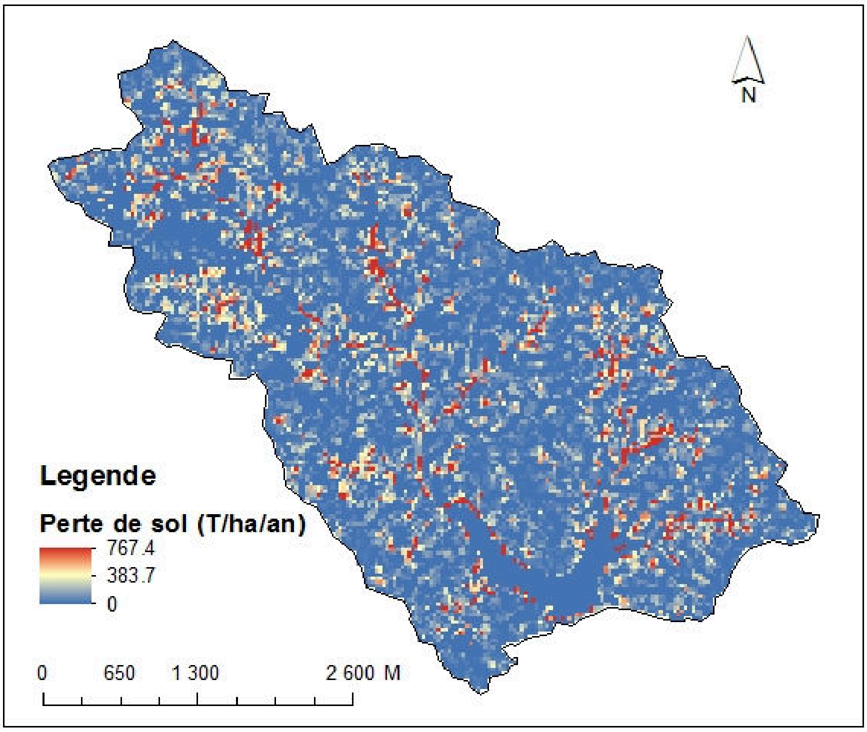

Fig. 6. Soil loss map of Babadou watershed

5 DISCUSSION

The universal soil loss equation (USLE) **[3]** was used to model the factors of soil water erosion through a GIS. As the results show, the R, K, and P factors in this equation vary very little. This is because the watershed of Babadou is relatively small (1630ha). This is not the case for factors C and LS.

The use of the Sentinel-2 image provides a better description of the land use and a better estimate of the C factor due to its resolution which is 10 to put. It is observed that the watershed of the hydro-agricultural dam of Babadou is subjected to a strong anthropization.

The results show an average soil loss of 6.9 t/ha/year, which represents a total annual soil loss of 11 247 t/year in the Babadou River watershed. Indeed, the soils are relatively well covered, with very little bare soil. The area of perennial crops is larger than that of annual crops. This plant cover spread evenly over the entire watershed reduces the impact of raindrops and brings to the soil organic matter that increases its structural stability. This helps to reduce soil loss. Our results confirm several studies, including that of **[9]**, which clearly show the role of vegetation in soil protection.

However, soil erosion is exacerbated in bare soils and annual crops due to the presence of low cover crops in June and July where rains are generally more erosive. This poses a threat to soil productivity on most of the annual cropland in the watershed of the Babadou hydro-agricultural dam.

In addition, soil losses in the Babadou River watershed are lower than those obtained by [1] and [2] who worked in central western Côte d'Ivoire.

6 CONCLUSION

The objective of this study, carried out on the watershed of the hydro-agricultural dam of Babadou, is to highlight the risks of water erosion and sediment transport. The universal soil loss equation (Wischmeier and Smith (1978) was used to model the factors of this phenomenon through a GIS, which allowed a good knowledge of soil erosion by water with a map of the most sensitive areas to erosion: the results show an average soil loss of 6.9 t/ha/year, which represents an average total soil loss of 11 247 t/year in the catchment area. The Babadou River can therefore be used as a basis for decision making for better management of soil and water resources. The monitoring and correction of certain factors involved in the erosion process in the most endangered areas may allow better management of soil and water resources.

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