

Contribution of a Geographical Information System to the Study of Soil Loss Dynamics in the Lobo Catchment (Côte d'Ivoire)

Jean-Philippe Attoungbré Deguy^{1*}, Alexis Yao N'Go¹, Hervé Kouakou Kouassi²,
Emile Gneneyougo Soro¹, Albert Tié Bi Goula¹

¹Laboratory of Geosciences and Environment, UFR Environmental Science and Management, Nangui Abrogoua University, Abidjan, Côte d'Ivoire

²Laboratory of Sciences and Technologies of Water, UFR Environment, University Jean Lorougnon Guédé, Daloa, Côte d'Ivoire

Email: *deguyjean@gmail.com

How to cite this paper: Deguy, J.-P.A., N'Go, A.Y., Kouassi, H.K., Soro, E.G. and Bi Goula, A.T. (2018) Contribution of a Geographical Information System to the Study of Soil Loss Dynamics in the Lobo Catchment (Côte d'Ivoire). *Journal of Geoscience and Environment Protection*, 6, 183-194.

<https://doi.org/10.4236/gep.2018.69014>

Received: July 30, 2018

Accepted: September 22, 2018

Published: September 25, 2018

Copyright © 2018 by authors and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution-NonCommercial International License (CC BY-NC 4.0).

<http://creativecommons.org/licenses/by-nc/4.0/>



Open Access

Abstract

The Lobo watershed is highly anthropogenic since it has become the main production area for cocoa and coffee in Côte d'Ivoire. It therefore seems important to quantify soil loss by water erosion in this region. The Wischmeier modeling was used to model the main factors involved in erosive phenomena. Crosscutting of thematic maps and the application of the USLE formulas made possible to evaluate the erosion rate at the watershed scale in 1986 and 2014. Although soil is susceptible to erosion and erosivity is increased, the results indicate a growth in soil loss estimated at 90.12%. Some agroforestry efforts are still possible to help reducing those soil losses.

Keywords

Water Erosion, Soil Loss, Universal Soil Loss Equation, Geographical Information System, Lobo

1. Introduction

Surface water erosion is a natural phenomenon with bad consequences in many countries around the world [1] [2] [3]. Controlling surface water erosion is a major challenge in areas with strong socio-economic interests. So, water erosion of soils is still a global environmental problem that degrades soil productivity and water quality. It accelerates the sedimentary process in lowland environments and increases the risks of flooding. The results are numerous: decline in

soil fertility, increase in the solid load of watercourses, silting up and siltation of water reservoirs [4], modification processes of regulation of the water cycle and the increase of pollutants in the receptors middles. Some authors [2] [3] [5] [6] [7] have analyzed the different processes of erosion and characterized erosion in its quantitative aspect. They spatialized or mapped the phenomenon of water erosion for sustainable management of soil and agriculture in a context of climate change in West Africa and particularly in Côte d'Ivoire. The Lobo watershed we study in this paper is located in the forest domain of Côte d'Ivoire [8]. Since, it is a favorable environment for many cash crops production (coffee, cocoa, rubber etc.). This area is strongly anthropized. Hence, in order to trigger a sustainable management policy, it appears important to characterize the soil losses that are taking place. Thus, the purpose of this study was particularly to characterize land degradation in a context of anthropogenic pressure on the Lobo watershed.

2. Study Area

The study area is the catchment of Lobo. It's located in west-central Côte d'Ivoire between $6^{\circ}05'$ and $6^{\circ}55'$ west longitude and between $6^{\circ}02'$ and $7^{\circ}55'$ north latitude. The catchment area of Lobo covers an area of about 12723 Km² and its bed develops about 597 km long (Figure 1). The Lobo River is one of the main tributaries on the left bank of the Sassandra River. The Lobo rises at an altitude of more than 400 meters south of the locality of Séguéla and flows into Sassandra not far from the town of Loboville.

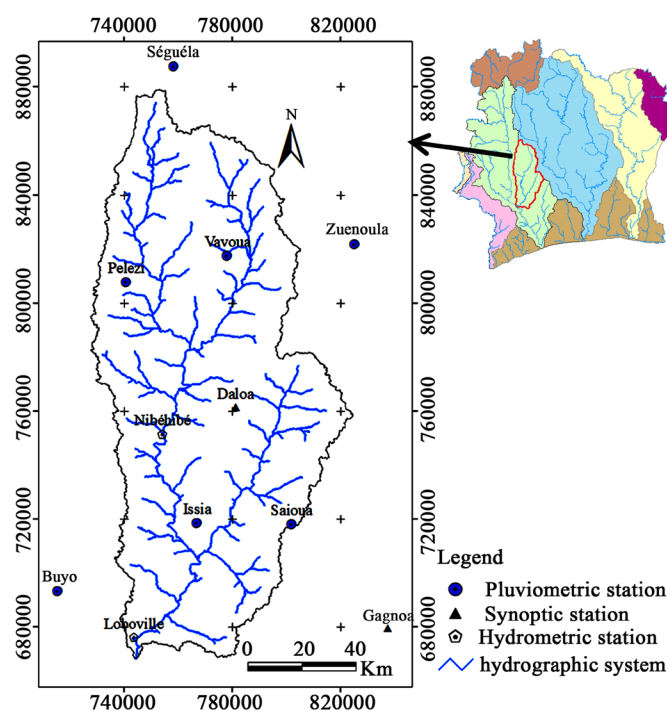


Figure 1. Presentation of the Lobo watershed.

The altitude vary between 163 m and 617 m and is generally as a peneplain. The watershed is composed of two major types of relief. These are the plains and the plate. The plains have an altitude between 160 and 240 m. The plate occupy most of the basin and have altitudes ranging from 240 to 320 m, with a crescent-shaped greenstone peak rising to an altitude of 617 m in the far north of the basin [9].

The geological formations of the Lobo watershed belong mainly to the Precambrian basement (Middle Precambrian) and are grouped into two major entities, namely magmatic and metamorphic rocks. The composition of magmatic rocks vary from granit to granodiorite. The metamorphic rocks of the basin are generally migmatite and shales in which the bed of the river is housed.

On the watershed Lobo, there are acrisols ferric, acrisols orthic the cambisols Eutric and cambisols ferralic [10]. The vegetation consists of forest relics associated with perennial crops (rubber, cashew, coffee and cocoa) or annual crops (rice, cassava, yam and market gardeners) [11].

3. Material and Methods

3.1. Material

The material is consisting of data SRTM, satellites images, rainfall, cartographics and measured devices. The data SRTM give a survey topographic of the area of globe. The DTM data used is resolution 30 m. The scenes 197 - 55, 197 - 56, 198 - 55 are satellite images of Landsat TM 1986 and OLI 2014 are registered and correct radiometrically and geometrically, were used in this study. Rainfall data were made available to us by the meteorological section of SODEXAM. The rainfall network (**Figure 1**) selected for this study has nine (9) positions. Rainfall data are available on a monthly time basis from 1919 to 2015. The data cartographic are various sources. The geologic map developed at a scale of 1/5,000,000 and the soil map at a scale of 1/4,000,000 [10] are used to put, in evidence the different structures present of the soil watershed Lobo.

3.2. Methods

Several models for estimating soil erosion exist with different degrees of complexity. The most widely used mathematical model is the universal soil loss equation (USLE). This Equation (1) groups all variables under six major factors [12]:

$$A = R \times K \times LS \times C \times P \quad (1)$$

or:

A loss rate = t/ha/yr,

R = erosivity of the rain,

K = soil erodibility,

LS = topographic factor integrating slope and slope length,

C = soil protection factor by vegetation cover,

P = factor expressing soil protection by agricultural practices.

Calculation of the factor R

The calculation of erosivity was done using [13] method. This method shows that there is a simple relationship between the average annual rainfall erosivity over a sufficiently long period (20 to 50 years) and the average annual rainfall during the same period. It is on this basis that the R calculations were carried out by applying the following Equation (2):

$$Ram = 0.50 * Ham \quad (2)$$

With Ram : Average annual rainfall erosion expressed in MJ·mm/ha·h·yr,
 Ham average annual rainfall in mm.

Calculation of soil erodibility K

Soil erodibility is an indicator of the ease with which soil particles break off. It results in the inherent resistance to detachment and transport particles by water. The K factor is a function of the texture, the organic matter content of the soil, and the permeability of the soil. The determination of the erodibility factor was based on the K soil variation table according to [14] to derive the soil erodibility values from the texture.

Calculation of the occupancy factor C

Factor C is defined as the ratio of bare soil loss under specific conditions to losses in soils corresponding to soils under an agricultural system [12] [15]. The value of factor C depends on the type and percentage of vegetation cover. Two satellite images of 1986 and 2014 were used for its determination. In this study, factor C was determined from the experiments of [12] in the United States. Primary forests are characterized by an index of 0.001 while heavily degraded areas have an index close to 1. The factor C is a function of land use. A column has been added to the land cover maps and coded according to the land cover type as described by [16] (Table 1).

Table 1. Coefficient of land use C according to the type of land occupation [16].

Type of land use	C Factor
Bare ground	1
Degraded forest	0.7
Degraded grass savannah	0.6
Culture mosaic	0.5
Savanna with trees and shrubs	0.3
Mangrove	0.28
Built surface	0.2
Wooded area	0.18
Rice paddy	0.15
Dense forest	0.001
Body of water	0

Calculation of the conservation factor P

The factor P describes the conservative human actions that are practiced to counteract water erosion. It usually ranges from 0 to 1, depending on the practices and the slope. However, given the fact that there are no anti-erosion practices adopted throughout the study area, this factor was considered equal to 1 [17].

Calculation of topographic factors LS

The slope criterion is used to highlight the ability of a runoff to detach and transport soil particles: the higher is the slope, the more the runoff will erode the soil. The topography parameter evaluated from two criteria (inclination of the slope and its length) and is calculated from a digital terrain model (DTM) resolution 30 m. The calculation factor LS Watershed Lobo, is performed using an algorithm QG is software. The shape of the USLE topographic factor (LS) for a slope segment was expressed by [18] as follows Equation (3):

$$LS = \frac{S_j \times (\lambda_j^{m+1} - \lambda_{j-1}^{m+1})}{(\lambda_j - \lambda_{j-1}) \times (22.13)^m} \quad (3)$$

Calculation of soil losses

A GIS incorporating the various factors (Figure 2) was used for the assessment and mapping of erosion rate at the watershed scale in 1986 and 2014. Each parameter is represented in the GIS by a cover or grid (grid or raster) representing the estimated values at the level of each surface element of the watershed. The superposition of the different data grids in the GIS gives us the value of the erosion rate at each surface unit (pixel).

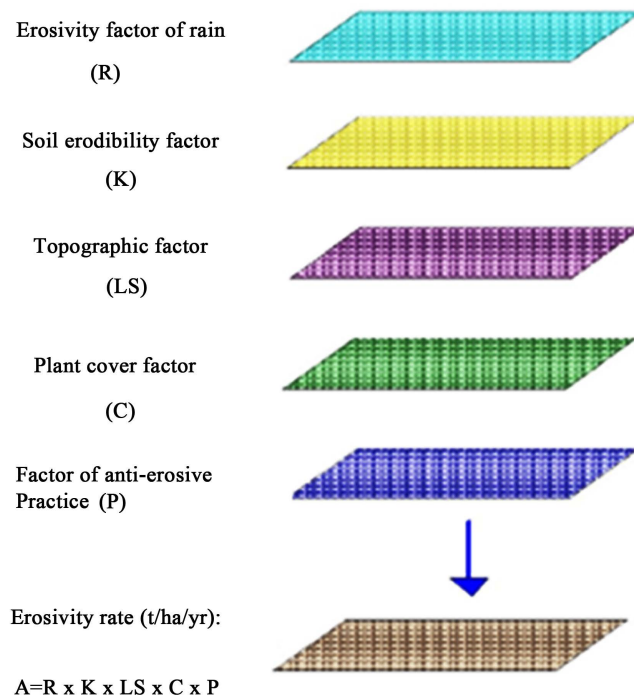


Figure 2. Organization chart of the USLE model.

4. Results and Discussion

4.1. Erosivity of the Rains (R)

Figure 3 shows the rainfall erosivity map of the Lobo watershed. Different erosivity levels presented as function of rainfall spatial distribution. Rainfall erosivity is stronger in the South in 1986 and from West and South in 2014 than in other parts of the Lobo watershed. It increases respectively from 551.95 to 699.03 MJ·mm/ha/h/yr in 1986 and from 509.91 to 812.40 MJ·mm/ha/h/yr in 2014. In general, the trend of the erosivity of the rains is increasing, because the average erosivity of the rains is 631.01 MJ·mm/ha/h/yr in 1986 and 671.77 MJ·mm/ha/h/yr in 2014.

4.2. Occupancy Factor C

Factor C provides information on land use. It varies from 0 to 1 in 1986 and in 2014. The different types of land use in the study area are built surface, bare soils, water bodies and vegetation cover mainly composed of degraded forests, fallow, rubber plantations, cocoa, cashew nuts. Low values of C correspond to different plantations and forests, while high values correspond to bare habitats and soils. In addition, the results show that the average C-factor values are 0.252 and 0.560 respectively lower for 1986 than in 2014. The increase in the area of bare soils and habitats contributes to this (**Figure 4**).

4.3. Erodibility of Soils K

Figure 5 shows the erodibility K of the Lobo watershed. The correspondence between the Soil texture and soil erodibility highlighted the most erodible soils

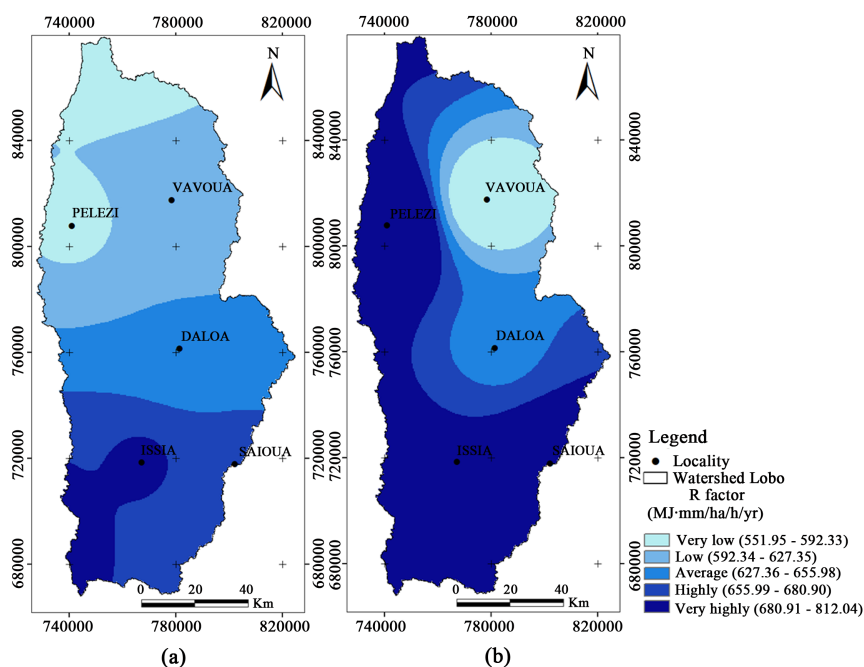


Figure 3. Erosivity of the rains: (a) 1976 to 1996; (b) 1997 to 2015.

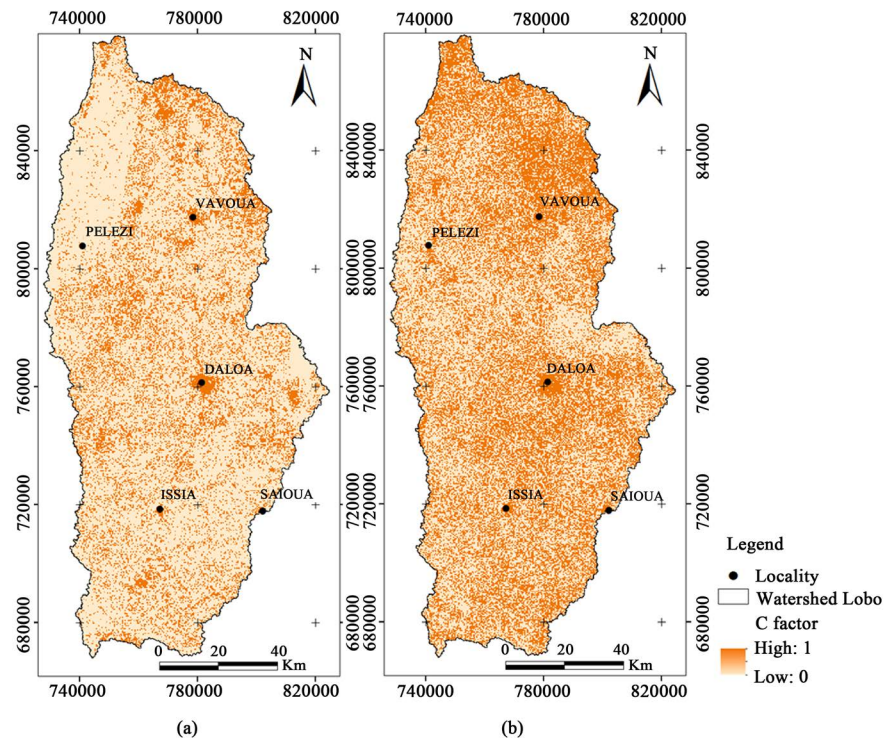


Figure 4. Plant cover factor C of 1986 (a) and of 2014 (b).

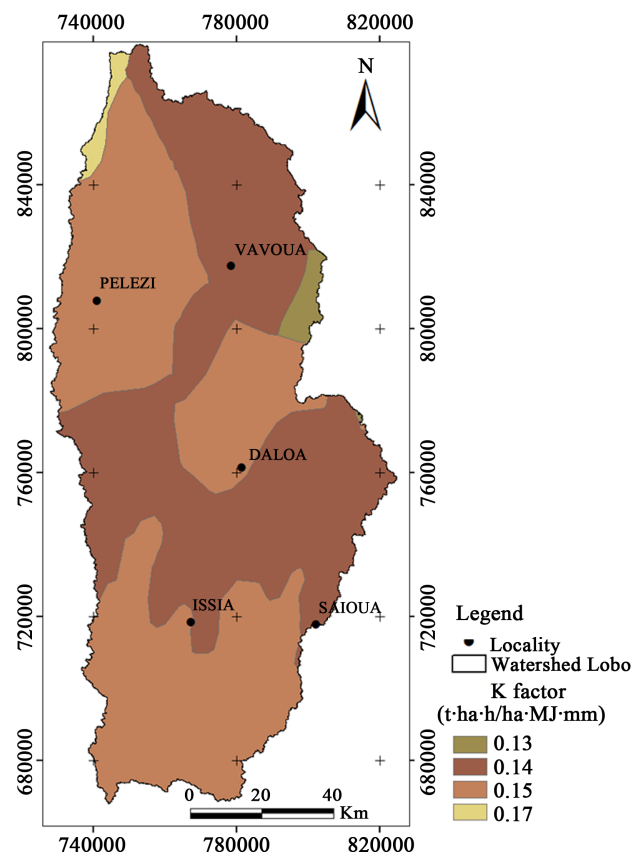


Figure 5. Soil erodibility K of the Lobo watershed.

in the watershed. The K factor varies between 0.13 to 0.17 t·ha·h/ha·MJ·mm. The most erodible soils correspond to Eutric Cambisols and Ferric Acrisols. The average soil erodibility factor is 0.145 t·ha·h/ha·MJ·mm. This indicates that these soils are moderately susceptible to erosion. The spatial distribution of the K factor shows that the most erodible soils are in the north and in the center.

4.4. LS Topographic Factors

The LS factor (**Figure 6**) highlights the importance of inclination and slope length in the water erosion process. The LS factor over the watershed range from 0 to 491.34 with an average average of 0.164. This value indicates that the topography of this basin is relatively flat. There is a contrast between the different watershed models. The Lobo flows from north to south. Slight slopes and steep slopes coexist mainly south of the watershed. The relief reveals a greater sensitivity to erosive processes south of the Lobo watershed. The lowest values of 0 to 5.81 of the topographic factor correspond to the bed of the stream and the plains. High LS values greater than 5.81 are associated with the massifs, the high valley and the steepest slopes on the Lobo watershed.

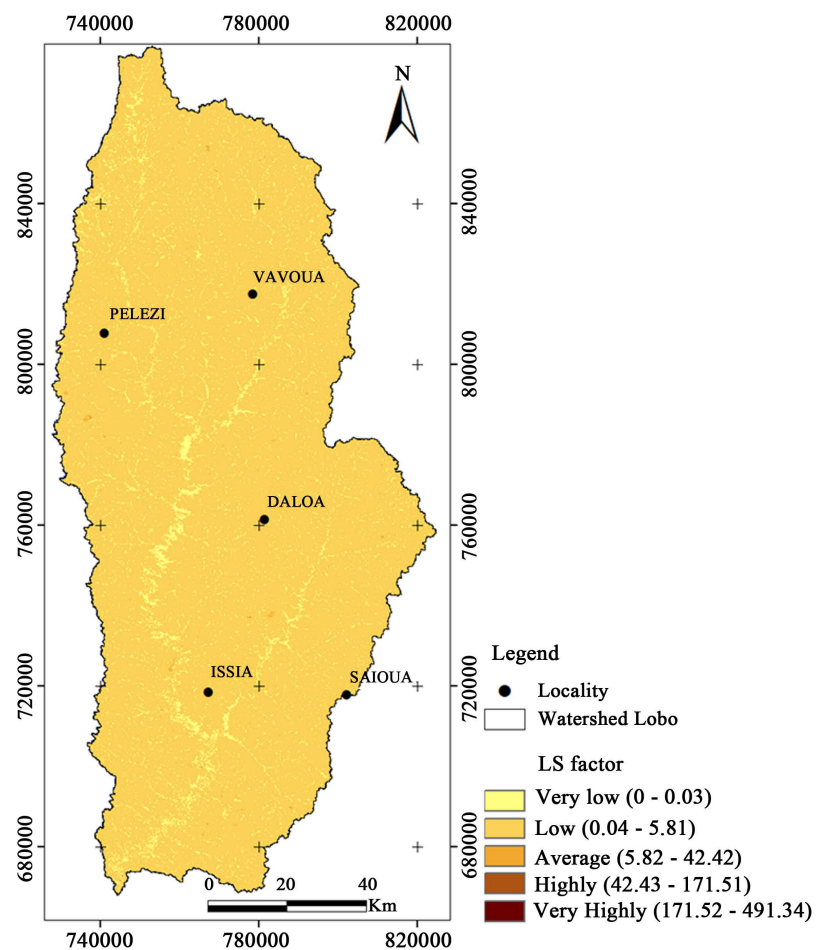


Figure 6. LS factor map.

4.5. Estimation of the Dynamics of Soil Losses

Soil loss values driven by water erosion in the Lobo watershed are grouped into 5 classes (**Figure 7**). The class of very low soil losses is identified respectively on 34.66% and 0.00% of the Lobo watershed for the years 1986 and 2014. This loss of soil is located around the hydrographic network. Low soil losses are scattered throughout the basin. This class occupies 29.05% and 52.83% respectively for the years 1986 and 2014. Concerning the class of average losses of grounds, it represents with 16.62% and 23.81% of the zone of study for the years 1986 and 2014. The areas of very strong and high soil loss correspond to regions of very strong and steep slope on the basin. These classes are estimated at 19.67% and 23.36% of the Lobo watershed. Average soil losses in the Lobo watershed are estimated at 16.09 t/ha/yr and 30.59 t/ha/yr respectively for the years 1986 and 2014.

5. Discussion

The Lobo watershed is highly anthropogenic because it is in the new loop of cocoa coffee. Wischmeier's model [12] was therefore used to model the main factors involved in erosive phenomena. This study indicates that soils are moderately susceptible to erosion with an average soil erodibility factor of 0.145 t-ha-h/ha-MJ-mm. As for the factor C, average values increased from 0.252 in 1986 to 0.560 in 2014. This increase factor C, which is owing to the growth of the grounds bare/settlement and the increased area of rubber, fields of cocoa and cashew nut. Several authors including [3] [8] have showed the decrease in this

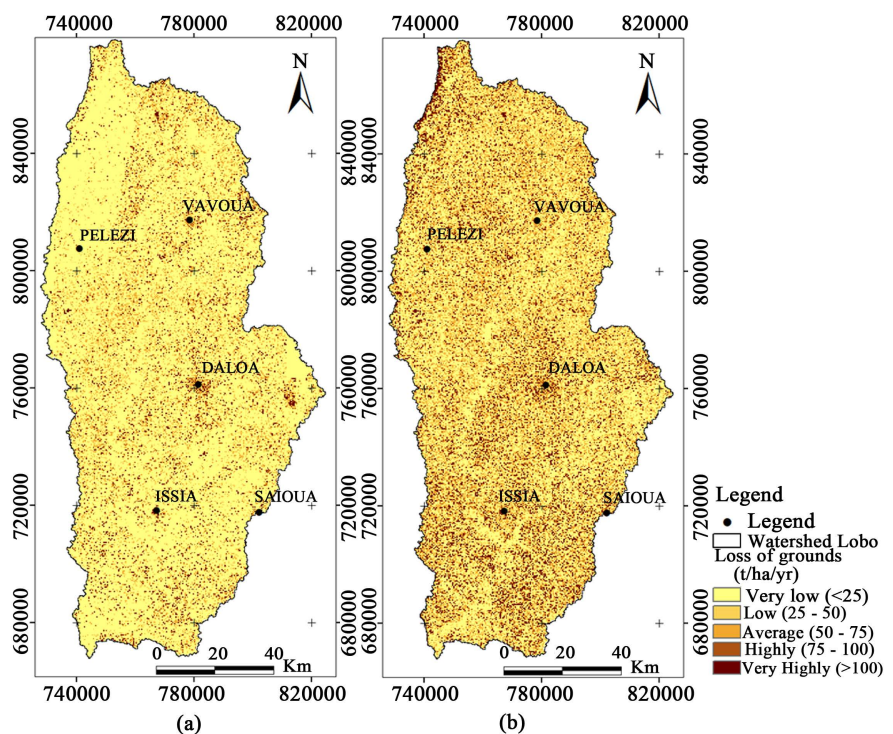


Figure 7. Map of soil losses from 1986 (a) and 2014 (b).

vegetation cover. In addition, the study shows a increase in rainfall erosivity in the Lobo watershed with an average of 631.01 MJ·mm/ha·h·yr in 1986 and 671.77 MJ·mm/ha·h·yr in 2014. Furthermore, the results obtained indicate a increase in soil losses estimated at 90.12%. Soil losses average soil increased from 16.09 t/ha/yr in 1986 to 30.59 t/ha/yr in 2014. These results show that water erosion is moderately active in 1986 and is strong in 2014 in this watershed. This average loss is higher than those found by [19] at Sassandra (26 t/h/yr), and [20] at the Aghien watershed (15 t/ha/yr), at that of [21] on the watershed of Bia (16 t/ha/yr) and that of [22] in the Walloon region (Belgium) (5 t/ha from 1991 to 2000). A highly degraded vegetation cover that was shown through a C factor growth of 122.22% drives the obtained increase of soil losses during the period 1986-2014. There was a decrease of both degraded forest and rainforest by 15.26% and 16.29% respectively. Similarly, there is an increase in bare soils/habitats and crops/fallow respectively of 4.00% and 27.56%. The rains erosivity increased to 6.46%. The combined effects of higher C factor and erosivity of rainfall explain the increase in soil loss in 2014 [16]. Although soils are susceptible to water erosion, development of cash crops could contribute to their protection. Some agroforestry efforts are still possible to help reducing those soil losses.

6. Conclusion

This work focused on the contribution of a geographic information system to the study of soil loss dynamics in the Lobo watershed. The quantification of soil losses in the Lobo catchment area was made using the Universal Ground Loss Equation (USLE) integrated into a Geographic Information System at the watershed scale. The results obtained show that the soils of the Lobo watershed have been affected by several factors favoring the erosion phenomenon namely erodibility, erosivity and vegetation cover. Analysis of the factors involved in soil loss indicates an increase in C-factor of 122.22% and erosivity of 6.46%. Average soil losses increased from 16.09 t/ha/yr in 1986 to 30.59 t/ha/yr in 2014, meaning 90.12% increase. This increase in soil loss is mainly arise to the higher of the C factor and the erosivity of the rains. Indeed, the emergence of home, bare soils and degraded forest had contributed of the growth of soil erosion in 2014. Efforts can be made through the development of agroforestry and reforestation to reduce C values to significantly reduce soil loss. The use of GIS allows the integration of new spatialised data of R and C at any time, thus allowing soil loss to be monitored over time.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Yjjou, M., Bouabid, R., El Hmaidi, A., Essahlaoui, A. and El Abassi, M. (2014)

- Modélisation de l'érosion hydrique via les SIG et l'équation universelle des pertes en sol au niveau du bassin versant de l'Oum Er-Rbia. *The International Journal of Engineering And Science (IJES)*, **3**, 83-91.
- [2] Kacem, L., Agoussine, M., Igmoullan, B., Amar H., Mokhtari, S. and Ait, B.Y. (2017) Application de la méthode d'analyse multicritère hiérarchique pour la quantification de perte en sol dans un sous-bassin montagnard-haute vallée de Tifnoute (Haut Atlas marocain). *Revue internationale de géologie, de géographie et d'écologie tropicales*, **41**, 493-502.
- [3] N'Go, Y.A., Kouadio, Z.A., Deguy, A.J-P., Hien, S.A., Goula, B.T.A. and Savané, I. (2018) Influence de la dynamique de l'occupation du sol sur la quantité de perte de sol au sud du bassin versant du Sassandra (Côte D'Ivoire). *International Journal of Advanced Research*, **6**, 830-838. <https://doi.org/10.21474/IJAR01/6918>
- [4] Coulibaly, T.J.H., Coulibaly, N., Koffi, D., Camara, M. and Savané, I. (2014) Cartographie des zones à l'origine de l'ensablement des canaux du bassin versant du Gourou (Abidjan-Côte d'Ivoire). *International Journal of Innovation and Applied Studies*, **6**, 642-653
- [5] Eblin, S.G., Yao, A.B., Anoh, K.A. and Soro, N. (2017) Cartographie de la vulnérabilité multifactorielle aux risques d'érosion hydrique des sols de la région d'Adiaké, sud-est Côtier de la côte d'ivoire. *Revue Internationale des Sciences et Technologie*, **30**, 197-216. <http://www.revist.ci>
- [6] Aké, G.É., Kouadio, B.H., Adja, M.G., Ettien, J.B., Effebi, K.R. and Biémi, J. (2012) Cartographie de la vulnérabilité multifactorielle à l'érosion hydrique des sols de la région de Bonoua (Sud-Est de la Côte d'Ivoire). *Physio-Géo. Géographie physique et environnement*, **6**, 1-42.
- [7] N'go, A.Y., Ama-Abina, J.T., Kouadio, A.Z., Kouassi, H.K. and Savané, I. (2013) Environmental Change in Agricultural Land in Southwest Côte d'Ivoire: Driving Forces and Impacts. *Journal of Environmental Protection*, **4**, 1373-1382. <https://doi.org/10.4236/jep.2013.412158>
- [8] Yao, A.B. (2015) Evaluation des potentialités en eau du bassin versant de la Lobo en vue d'une gestion rationnelle (Centre Ouest de la Côte d'Ivoire), Thèse Unique de Doctorat de l'Université Nangui-Abrogoua, Côte d'Ivoire, 225 p.
- [9] Avenard, J.M. (1971) Aspect de la géomorphologie in Avenard J. M., Eldin M., Girard G., Sircoulon J., Touchebeuf P., Guillaumet J. L., Adjanohoun E. and Perraud A. (Eds.), Milieu naturel de Côte d'Ivoire. Mémoire ORSTOM, Paris, 8-73.
- [10] FAO-Unesco (1976) Carte mondiale des sols, VI Afrique, 337 p.
- [11] Yao, A.B., Goula B.T.A., Kouadio, Z.A., Kouakou, K.E., Kane, A. and Sambou, S. (2012) Analyse de la variabilité climatique et quantification des ressources en eau en zone tropicale humide. Cas du bassin versant de la Lobo au Centre-Ouest de la Côte d'Ivoire. *Revue Ivoirienne des Sciences et Technologies*, **19**, 136-157.
- [12] Wischmeier, W.H. and Smith, D.D. (1978) Predicting Rainfall Erosion Losses—A Guide to Conservation Planning. Agricultural Handbook, USDA, Washington, 537 p.
- [13] Roose, E. and Lelong, F. (1976) Les facteurs de l'érosion hydrique en Afrique Tropicale. Études sur petites parcelles expérimentales de sol. *Revue de géographie physique et de géologie dynamique*, **18**, 365-374.
- [14] Stone, R.P. and Hilborn, D. (2000) Universal Soil Loss Equation (USLE). Ontario Ministry of Agriculture and Food, Agriculture and Rural Division; Factsheet, Order No. 00-001.

- [15] El Garouani, A., Chen, H., Lewis, L., Tribak, A. and Abahrour, M. (2008) Cartographie de l'utilisation du sol et de l'érosion nette à partir d'images satellitaires et du SIG Idrisi au Nord-est du Maroc. *Revue Télédétection*, **8**, 193-201.
- [16] Payet, E., Dumas, P. and Pennober, G. (2012) Modélisation de l'érosion hydrique des sols sur un bassin versant du sud-ouest de Madagascar, le Fiherenana. *VertigO-la revue électronique en sciences de l'environnement*, **11**.
- [17] Issa, L.K., Lech-Hab, K.B.H., Raissouni, A. and El Arrim, A. (2016) Cartographie quantitative du risque d'érosion des sols par approche SIG/USLE au niveau du bassin versant Kalaya (Maroc Nord Occidental). *Journal of Materials and Environmental Science*, **7**, 2778-2795.
- [18] Foster, G.R. and Wischmeier, W.H. (1974) Evaluating Irregular Slopes for Soil Loss Prediction. *Transactions of the ASAE*, **17**, 305-309.
- [19] N'Go, Y.A. (2015) Hydrologie et dynamique de l'état de surface des terres dans le sud-ouest de la Côte d'Ivoire: Impacts et moteurs de dégradation. Thèse de Doctorat, D'État Ès-Sciences Naturelles, 220 p.
- [20] Koffi, K.J.-P. (2017) Analyse hydro-géomorphologique de Bassin Versant et vulnérabilité à la pollution des eaux de surface: Cas de la lagune Aghien, Sud de la Côte d'Ivoire. Thèse de Doctorat, Université Nangui Abrogoua, Côte d'Ivoire, 232 p.
- [21] Méléndje, N. (2016) Modélisation de la dynamique hydrologique et du flux des sédiments dans le lac du barrage hydroélectrique d'ayame1. Thèse de Doctorat, 3 ème cycle de l'Université Nangui Abrogoua, (Abidjan) Côte d'Ivoire, 267 p.
- [22] Dautrebande, S. and Sohier, C. (2006) L'érosion hydrique et les pertes en sol agricoles en Région Wallonne. Dossier scientifique réalisé dans le cadre de l'élaboration du Rapport analytique 2006 sur l'Etat de l'Environnement wallon, 122 p.