Scientific Research Publishing

Agricultural Sciences, 2023, 14, 176-195
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Impacts of Agricultural Activities on Land Degradation along the Bomboré River in Burkina Faso

Joseph Nomwindé Kabore[1,2*], Elie Serge Gaëtan Sauret[3], Wennegouda Jean Pierre Sandwidi[4], Raoul Christian Ouedraogo[5,6], Brahima Sorgho[6]

[1]Senghor Campus, Senghor University, Ouagadougou, Burkina Faso
[2]General Office of Plants Productions, Ministry of Agriculture, Animal and Fishery Resources, Ouagadougou, Burkina Faso
[3]National Center for Scientific and Technological Research/National Institute for the Environment and Agricultural Research, Farakôba Research Station, Bobo Dioulasso, Burkina Faso
[4]Higher School of Engineering, University of Fada N'Gourma, Fada N'Gourma, Burkina Faso
[5]Alliance for the Green Revolution, Ouagadougou, Burkina Faso
[6]Molecular Chemistry and Materials Laboratory, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso
Email: *nomwinde@yahoo.fr, saurelie517@yahoo.fr, wsandjp@yahoo.fr, oraou@yahoo.fr, sobrah20@yahoo.fr

How to cite this paper: Kabore, J.N., Sauret, E.S.G., Sandwidi, W.J.P., Ouedraogo, R.C. and Sorgho, B. (2023) Impacts of Agricultural Activities on Land Degradation along the Bomboré River in Burkina Faso. *Agricultural Sciences*, **14**, 176-195.
https://doi.org/10.4236/as.2023.142012

Received: January 18, 2023
Accepted: February 12, 2023
Published: February 15, 2023

Abstract

Land along the Bomboré River in the rural commune of Mogtédo in Burkina Faso is experiencing degradation. The explanatory causes of this degradation constitute the subject of this study. To do this, a survey was conducted among agricultural producers deployed along the watercourse. Soil profiles were described and samples were taken to analyze pH, soil organic carbon, soil organic matter, total nitrogen, and texture. The RUSLE model approach based on landstat8 OLI/TIRS and SRTM satellite images dated December 17, 2021 with fairly good radiometric, spatial, and spectral resolution was used to calculate the land loss rate. In terms of results, the potentially irrigable areas that spread out on both sides of the banks of the river cover 209.23 ha with a perimeter of 6.16 km. The number of irrigators is 26 producers and they grow 17.92 ha of vegetables. Soil analyzes indicate the presence of a moderate acid on the vertisol with a pH between 5.57 and 5.86. On the depth 0 - 30 cm of the horizon, the color of the horizons ranges from 5YR4/2 on the talweg and on the right bank to 7.5YR3/2 on the left bank and presents no risk of salinity because the electrical conductivity measured is less than 1dS/cm. The diagnosis of hydromechanical equipment shows that producers use 46 motor pumps for irrigation, of which 15 motor pumps run on gasoline and 31 motor pumps on butane gas with a ratio of 1.7 motor pumps per producer. The number of Polyvinyl Chloride (PVC) pipes used by producers in combination with a motor pump gives an average of 44 per farmer. In terms of mineral fertilization, the gross doses used by producers are 415.53 kg/ha of NPK and 201.55 kg/ha of urea, while the quantities of phytosanitary products are 3.99 l/ha of pesticides and 1.42 l/ha of herbicides. Agricultural activities emit about 222,436.66 kgCO_2eq into the atmosphere, whose emissions from motor pumps represent 84.52% of these total emissions. The land loss estimate gives an average rate of 2.30 t/ha/year of land loss. This loss is due to the effects of poor agricultural practices, water erosion, and the drainage channels and gullies created by the anarchic installation of dwellings around the edges of the river. This study calls for more monitoring actions to sustainably safeguard the soil and water resources of this river which contribute to the survival of more than 73,214 inhabitants.

Keywords

Agricultural Irrigation, Land Degradation, RUSLE Model, Erosion Rate, Environment

1. Introduction

A Sahelian country with an essentially semi-arid climate, Burkina Faso is faced with relatively difficult agro-ecological conditions due to climatic deterioration and increasing anthropogenic pressure.

Burkinabè agriculture is mainly driven by small family farms of extensive types, weakly mechanized [1]. Plant production is dominated by cereals (sorghum, millet, maize, rice, and fonio) which occupy more than 70% of the areas sown annually and constitute the staple diet of the majority of the population [2]. These plant productions are essentially rainfed and constrained by rainfall variability.

Agriculture in Burkina Faso is characterized by two types of production, namely rainfed and irrigated agriculture [3]. Agricultural areas are estimated at 4,272,786 ha for rainfed crops and 11,690 ha for irrigated crops [1].

Burkina Faso experienced major droughts in the 1970s which seriously hampered agricultural production and led to recurrent food crises [4]. Drawing lessons from these drought waves, delays, and rainfall deficits, the development of irrigation through the mobilization of water, and the development and the enhancement of irrigated perimeters and lowlands constitute strategic axes for the ministry in charge of agriculture [5]. Irrigated agriculture is thus a promising alternative for securing agricultural production and a certain financial windfall for irrigators [6]. It is in this context that the Nakanbé-Bomboré sub-watershed, which has enormous hydro-agricultural potential and arable land, is the subject of agricultural operations along its Bomboré River. This river has been known for several decades as an intensive abstraction of surface water for irrigation. The development of irrigated land has led to a change in the balance of agro-hydro systems linked to erosion and eutrophication phenomena [7]. The eutrophication phenomenon is an environmental reaction to an increase in invasive aquatic plants. Farms that are located upstream of water reservoirs in the Nakanbé sub-watershed are experiencing specific degradation [8]. In the Nakanbé-Bomboré catchment area, in recent decades, there has been an increase in the number of producers along the river using motor pumps as a means of drainage for vegetables. Bad practices (siphoning, exploitation of river banks, over-irrigation, etc.) and applications of agricultural inputs (misuse of fertilizers and pesticides) contribute to the silting up/siltation of the river, and the decline in soil fertility and water pollution [9].

The lack of appropriate measures for the development and conservation management of water and soil in agricultural watersheds remains one of the fundamental causes of the dysfunction and decline in agricultural productivity of irrigated perimeters and lowlands [10] [11].

In recent years, work on the rate of specific degradation in the water reservoirs of Mogtédo [12] and in the sub-watersheds of Burkina Faso [13] in connection with agricultural activities was carried out. Other works have also focused on: 1) the evaluation of the technical performance of irrigation in Burkina Faso [5]; 2) the characterization and modeling of groundwater [14] [15]; 3) the contribution of geomorphology to the process of designing river restoration projects and the use of water resources for agricultural purposes [16] [17] [18]; 4) integrated management of soil [17] fertilization under vegetable production [19]. Despite the plurality and diversity of studies carried out, the problem of land degradation along the banks of the rivers under vegetables in general and that of the Bomboré River did not receive any particular interest. However, these banks of perennial or intermittent watercourses in Burkina Faso constitute ecosystems and a continuum of biodiversity conservation rich in flora and fauna which deserve an in-depth look due to the impacts of human activities and climate change as to their viability.

This study will help to know which extent agricultural activities destroy the land in the Bomboré River area in order to promote the adoption of good agricultural practices around water reservoirs.

It is an essential step in planning actions to safeguard the ecosystems of watercourses, in order to make it possible to diagnose and suggest appropriate solutions for sustainable land and water resources management.

2. Material and Methods

2.1. Study Zone

The Bomboré River is located in the Nakanbé-Bomboré sub-watershed, one of the forty constituent sub-watersheds of the Nakanbé catchment [20]. The study area is located in longitude 0˚51.818'W and latitude 12˚16.277'N (**Figure 1**). According to the administrative subdivision of Burkina Faso, the study area falls under the Central Plateau region and is located at the rural commune of Mogtédo, Ganzourgou province.

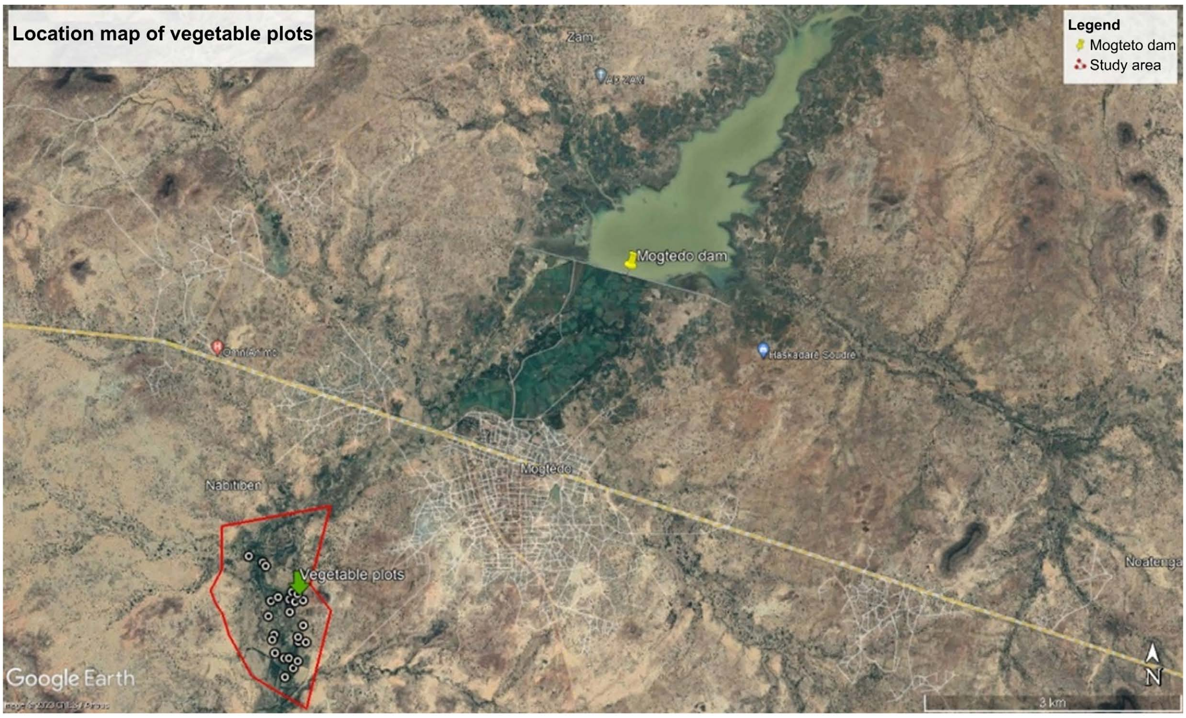

Figure 1. Location map of the study area.

Climate of the Nakanbé-Bomboré sub-watershed is characterized by a winter season from June to September and a dry season from October to May. The average annual rainfall collected in Mogtédo over the past ten years' ranges from 655 mm to 863 mm.

2.2. Field Investigation

Data was collected from producers located along the Bomboré River and owners of agricultural plots. An elaborate questionnaire was submitted to each producer to:

- Collect quantitative data on their farms: number of motor pumps in possession, daily operating time of each motor pump, fuel consumption per day, irrigation time, quantity of inputs used (NPK, urea, pesticides, compost, etc.), and sown agricultural speculations, etc.
- Know the area of each farm and validate the information collected by a GPS survey.

2.3. Soil Prospecting

A pedological survey was carried out following two toposequences going from the top of the river banks to the talweg following the line of greatest slope [21]. On each site, three pits or soil profiles were opened, one on each bank and one in the talweg. The soil profiles were opened to a depth of at least 1.20 m and the description was made according to [22], guidelines and classified according to the "Commission Pédologique et Cartographique de Sol [23]" of France.

Six soil samples were taken from the 0 - 30 cm horizon at the level of the left and right banks of the river as well as in the talweg. These samples were the subject of physico-chemical analyzes carried out at the National Soil Office (BUNASOLS). They concerned:

- pH: This analysis was carried out using the glass electrode and calomel reference electrode method with a soil/water ratio of (1/2.5).
- The soil organic carbon rate was obtained with the Walkey & Black method. The carbon is oxidized by potassium dichromate ($K_2Cr_2O_7$) in sulfuric medium (H_2SO_4).
- The rate of organic matter: This rate was deducted from that of the organic matter knowing the rate of carbon and according to the formula below:

$$\%OM = \frac{\%Carbon \times 100}{58} \quad (1)$$

- Total nitrogen: This measurement was made by the Kjeldhal method. The sample, sieved at 0.5 mm, is subjected to the action of sulfuric acid (H_2SO_4) and catalysts (Cu, Se, Na).
- Assimilable phosphorus: The Bray method was used. This method combines the extraction of phosphorus in an acid medium with the complexation, by ammonium fluoride (NH4F), of aluminum bound to phosphorus.
- Available potassium: This measurement was carried out using a flame photometer by comparing the intensities of the radiation emitted by the potassium atoms with those of the standard solutions.

Tthe five-fraction particle size: The international method adapted to the "Robinson Khöln" pipette made it possible to make the measurements.

It includes the steps of:

- Destruction of organic matter by peroxide (H_2O_2).
- Dispersion of clays with sodium hexametaphosphate $(NaPO_3)_6$.
- Sampling during sedimentation at a precise depth of the non-seeable elements using a "Robinson" pipette.
- Weighing the solid residue of each sample after evaporation.
- Separation by sieving of fine sands and coarse sands.

Sedimentation is based on Stockes' law. According to this law, the speed of a spherical particle settling under the influence of gravity in a liquid of known density and viscosity is proportional to the square of the radius of the particle.

$$V = \frac{2(D_1 - D_2) * gr^2}{9p} \quad (2)$$

where:

D_1 = density of the particle in g/cm^3.

D_2 = density of the liquid in g/cm^3.

g = acceleration due to gravity = 9.81 m/s^2.

r = radius of the particle in cm.

p = viscosity of the liquid in g/cm/s.

2.4. Estimation of CO_2 Emitted

Calculation of CO_2 emitted quantities by the motor pumps was carried out with the tool Ex-Ante Carbon-Blanc Tools (EX-ACT-v9) developed by FAO in 2011 which follows of IPCC lines for national greenhouse gas inventories (2006, 2014, 2019). This tool makes it possible to estimate the impacts of projects and programs in agriculture and forestry according to carbon balance. The CO_2 emission factors of fertilizers and pesticides are proposed in Table 1 and Table 2 [24].

The butane emission factor is 230 kg CO_2eq per 01 kg of butane consumed, while that of gasoline is 2.29 kg CO_2eq per 01 liter [25].

To obtain the emissions, the nutrient dose is multiplied by the corresponding emission factor. Thus, for binary or ternary fertilizers, a summation of the emissions of each nutrient was made. The formula for calculating CO_2 emissions per hectare (kg CO_2eq/ha) is as follows [26]:

$$\frac{\text{kg CO}_2\text{eq}}{\text{ha}} = \text{doseN}\left(\frac{\text{kg N}}{\text{ha}}\right)\times 5.29 + \text{doseP}\left(\frac{\text{kg P}_2\text{O}_5}{\text{ha}}\right)\times 0.94 + \text{doseK}\left(\frac{\text{kg K}_2\text{O}_5}{\text{ha}}\right)\times 0.5 \tag{3}$$

2.5. Land Loss Estimate

The assessment of the risks of physical degradation concerns the first 30 centimeters. The risks are assessed using the equation below [27] [28]. The PIERI index is a ratio between the quantity of organic matter in a soil and its mineral adsorption surface below which the maintenance of the structural structure is no longer assured.

Table 1. CO_2 emission factor of fertilizers.

Input Type	Nutrient Unit	Kg CO_2/kg Nutrient
	kg N	5.29
Ternary Fertilizer	kg P_2O_5	0.94
	kg K_2O	0.51

Source: [24].

Table 2. CO_2 emission factor of pesticides.

Entitled	Kg CO_2/kg of Active Ingredient	Kg CH_4/kg of Active Ingredient	Kg N_2O/kg of Active Ingredient
Herbicide	8.33	0.0254	0.00022
Fungicide	5.53	0.018	0.00015
Insecticide/Pesticide	23.7	0.054	0.00063

Source: [24].

$$S_t = \frac{(\mathrm{OM})\%}{(\mathrm{Clay}+\mathrm{Silt})\%} * 100 \tag{4}$$

- If $S_t < 5\%$, unstructured horizon, high sensitivity to erosion.
- If $5\% < S_t < 7\%$, unstable horizon with high risk of destruction.
- If $S_t > 9\%$, horizon presenting no immediate risk of destruction.

The surface crusting index (I_c) [28] is determined according to the following formula:

$$I_c = \frac{1.5L_f + 0.75L_g}{A + (10 \times \mathrm{OM})} * 100 \tag{5}$$

with, L_f: fine silt (2 - 20 µm) %.

L_g: coarse silt (20 - 50 µm) %.

A: clay < 2 µm.

OM: organic matter.

- If $I_c < 1.5$, low risk of deterioration.
- If $1.5 < I_c < 2.5$, risk of average degradation.
- If $I_c > 2.5$, high risk of deterioration.

The revised RUSLE model, which quantifies soil loss, was used to characterize annual soil loss rate in the study area. The implementation of the RUSLE model requires data on topography, land cover, climatology and pedology.

The RUSLE model considers erosion as a multiplicative function taking into account the erosivity of precipitation (factor *R*) and the resistance of the environment (factors *C*, *K*, *LS*, *P*). Each factor is a numerical estimate of a specific component that affects the severity of soil erosion at a given location [29].

The data set created for this study is made up of bibliographic data and a Digital Elevation Model (DEM) of the area, downloaded from the United States Geological Survey (USGS) site, pedological (soil types) and rainfall data acquired from BUNASOLS and the National Agency for Aviation and Meteorology (ANAM) of Burkina Faso. All the data acquired was used to create a spatially coherent vector and raster database that can be used in a Geographic Information System (GIS) environment, in particular ArcGis 10.2. Digitization, extraction of the study area, georeferencing and creation of attribute tables were the main stages of data preprocessing. The basic equation of the RUSLE model is:

$$A = R \times K \times LS \times C \times P \tag{6}$$

where:

A is the soil loss rate t/ha/year.

R is the erosivity of rainfall (MJ·mm/ha·h·year).

K is the soil erodibility (th/ha·MJ·mm).

LS is a topographic factor (*L* in m, *S* in %).

C represents the vegetation cover.

P represents agricultural activities and practices and erosion control projects.

The *R* factor was determined from rainfall data for the last thirty years in the study area from 1990 to 2020, acquired from ANAM. He corresponds to the equation of [30]:

$$R = 0.043 \times P^{1.610} \tag{7}$$

where *P*: average annual precipitation in mm.

The *K* factor reflecting the erodibility of soils or its susceptibility, and the rate of soil erosion was established on the mapping of soil types in the study area and determined from the Wischmeier & Smith equation (1978):

$$K = \frac{\left(2.1 * 10^{-4} * M^{1.14}\right) * (12 - a) + 3.25 * (b - 2) + 2.5 * (c - 3)}{100} \tag{8}$$

where *M* is calculated by the formula below:

$$M = (\%\text{fine sand} + \text{silt}) \times (100 - \%\text{clay}) \tag{9}$$

a is the percentage of organic matter.

b is the permeability code.

This is the structure code.

The *LS* factor is a function of the length and steepness of the terrain slopes [31]. In this study, the formula developed below [32] adopted by several authors was used:

$$LS = \left(\text{length of the Slope} \times \frac{\text{resolution}}{22.1}\right)^m \times \left(0.065 + 0.045 \times \text{Slope}(\%) + 0.0065 \times \text{Slope}(\%)^2\right) \tag{10}$$

The parameter "*m*" is chosen according to the slopes of the watershed studied according to the indications below (**Table 3**).

The *C* factor could not be calculated from the line graph proposed [34] because of the impossibility of determining the percentage of soil covered by the canopy and the height of the different types of vegetation cover. The *C* factor was determined from the Normalized Deviation of the Vegetation Index (NDVI) as recommended by [35], who estimate that this *C* factor also depends on the nature of the vegetation and the percentage of plant cover. The *C* factor is a function of the Normalized Difference Vegetation Index (NDVI) commonly used in the analysis of satellite images. It is calculated by:

$$\text{NDVI} = \frac{\text{NIR} - R}{\text{NIR} + R} \tag{11}$$

The *C* factor varies between 1 for a bare fallow and 0.001 for a completely covered ground (Wischmeier & Smith, 1978). It is calculated by:

$$C = \frac{1 - \text{NDVI}}{2} \tag{12}$$

Table 3. Value of m according to slope.

Settings	Slope (%) < 1	1 ≤ Slope (%) < 3	3 ≤ Slope (%) < 5	Slope (%) ≥ 5
"*m*" Value	0.2	0.3	0.4	0.5

L and *S* factors can be estimated separately from NTMs [33].

The *P* factor, which reflects agricultural and soil conservation practices (anti-erosion practices, contour plowing, ridging, ridging, etc.), could not be determined on the Landsat-TM satellite images and therefore the threshold value was set to 1 [36].

The RUSLE model is implemented by crossing the parameters with each other through arithmetic rules and Boolean operators in order to produce a new value in the composite layer, here representative for each pixel of soil losses [33]. The P factor can be approximated by the equation:

$$P = 0.2 + 0.03 \times \text{Slope}(\%) \quad (13)$$

3. Results

After analyzing the data collected in the field, the results obtained are presented according to the main themes relating to the land resources of the study area, the means of extracting water for crop irrigation, the inputs used for agricultural production, CO_2 emitted by agricultural inputs and equipment as well as the rate of land loss.

3.1. Land Resources

The results obtained from the soil survey show that, along the Bomboré River, the soils on the banks are of vertisol type with depths that are greater than 1.20 m. The texture is clayey-loamy in the horizon of 0 - 30 cm on the whole of the two banks and the thalweg. It becomes clayey in the underlying horizons. The color of the horizons ranges from 5YR4/2 (black reddish gray) in the thalweg to 7.5YR3/2 (black brown) on the left bank and 5YR3/2 (reddish gray) on the right bank.

The results of physico-chemical analyze of soil samples over the 0 - 30 cm depth are presented in **Table 3** and compared with the FAO and BUNASOLS standards of 1994 (**Table 4**). They indicate the presence of three geomorphological units which show a low organic matter rate of 0.72% on the left bank and an average of 1.64% on the right bank. The material content is high (2.10%) at the level of the thalweg.

The soil on the left bank is highly acidic (pH = 5.57) while the soils on the talweg and on the left bank are moderately acidic with a water pH between 5.6 and 6. Electrical Conductivity (EC) measured shows that the soil along the river presents no risk of salinity for the crops grown, it is less than 1000 uS/cm.

The nitrogen rate is very low in the three morpho-pedological units from the left bank to the right bank and in the talweg (**Table 5**). As for assimilable phosphorus (Pa), its value is low (9 mg/kg) on the left bank but it is high (26 mg/kg) in the thalweg, and very high (45 mg/kg) on the right bank (**Table 5**). The available potassium (Kd) in the soil shows a very low value (22 mg/kg) on the left bank, average (61 mg/kg) and high (106 mg/kg) respectively in the talweg and on the right bank (**Table 5**).

Table 4. Soil analysis results on depth 0 - 30 cm.

Parameters Analyzed	N (mg/kg)	Pa (mg/kg)	Kd (mg/kg)	CE (uS/cm)	Clay (%)	Silts (%)	Sands (%)	pH	VS (%)	MO (%)
Left Bank	6	9	22	131	39.50	46.76	13.74	5.57	0.42	0.72
Right Bank	33	45	106	636	27.50	65.82	6.68	5.65	0.95	1.64
Talweg	19	26	61	364	43.75	46.37	9.88	5.86	1.22	2.10

Table 5. Soil fertility class standards.

Class		Very Low	Low	AVERAGE	Raised	Very High
MO	Quoting	1	2	3	4	5
	%	<0.5	0.5 - 1.0	1.0 - 2.0	2.0 - 3.0	>3
Total #	Quoting	1	2	3	4	5
	%	<0.02	0.02 - 0.06	0.06 - 0.10	0.10 - 0.14	>0.14
Pa	Quoting	2	2.5	3	3.5	4
	ppm	<5	05 - 10	10 - 20	20 - 30	>30
Point	Quoting	2	2.5	3	3.5	4
	ppm	<100	100 - 200	200 - 400	400 - 600	>600
Kd	Quoting	2.5	2.75	3	3.25	3.5
	ppm	<25	25 - 50	50 - 100	100 - 200	>200
Kt	ppm	<500	500 - 1000	1000 - 2000	2000 - 4000	>4000
	Quoting	2.5	2.75	3	3.25	3.5
CEC	Meq/100g	<5	05 - 10	10 - 15	15 - 20	>20
	Quoting	2	2.5	3	3.5	4
V	%	<20	20 - 40	40 - 60	60 - 80	>80
	Quoting	2	2.5	3	3.5	4
S	Meq/100g	<1	1 - 6	6 - 11	11 - 16	>16
	Quoting	1	2	3	4	5
pH	Value	>9.0 <4.5	8.5 - 9.0 4.6 - 5.0	7.9 - 8.4 5.1 - 5.5	7.4 - 7.8 5.6 - 6.0	6.1 - 7.3
	Quoting	1	2	3	4	5

Source: [28].

3.2. Means of Pumping

The means of pumping water for irrigation that the study listed on the site showed that there were motor pumps fitted with pipes made of Polyvinyl Chloride (PVC). All of the equipment thus listed is used to exploit the water of the Bomboré stream for the irrigation of furrow crops on the banks. The total number of motor pumps on the site was forty-six including 31 motor pumps between 1 and 5 years old and sixteen others between 5 and 10 years old. For their operation, fifteen motor pumps used regular gasoline (Super 91) while the thirty-one others were powered by butane gas.

The PVC pipes used on the study site vary in size and quantity per operator for an estimated total length of approximately 6800 m. A quantity of 10 to 80 PVC pipes is used by producers working on the site, including an average of 44 pipes per operator. The vegetable plots closest to the river are less than 5m away while the furthest are more than 500 m.

The operators listed on the site, twenty-six in number, operate a total area of approximately 17.92 ha due to an average of 0.7 ha per producer; the minimum area per producer being 0.1980 ha and the maximum 2.2985 ha. With regard to the total number of operators and motor pumps, a ratio of approximately two motor pumps per producer on the site can easily be derived.

The operators listed mainly come from four surrounding localities and the hired workforce by producer varies from 4 to 15 people for the two production campaigns of dry and wet season. Not all the plots located along the Bomboré River have been developed to facilitate crop irrigation.

3.3. Inputs Used

Producers who operate market gardening along the river use huge quantities of mineral fertilizers for cropping. Gross input doses of fertilizers used by producers are summarized in **Table 6** below.

The investigation showed that the mineral fertilizers used on the site are NPK of formulation 14-23-14 and urea (46%). In the dry campaign, the raw doses of fertilization are 468.5 kg/ha of NPK and 262.15 kg/ha of urea. Referring to the doses recommended by popularization in Burkina Faso, which are 300 kg/ha of NPK and 150 kg/ha of urea in vegetables, the surplus of fertilizers applied in the dry season is 168.52 kg/ha for NPK and 112.15 kg/ha for urea. In the wet campaign, the surplus is 62.54 kg/ha of NPK and 8.96 kg/ha of urea.

In the dry season, producers use more than 28 liters of herbicides and 91 liters of pesticides to treat vegetable crops, *i.e.* 1.56 l/ha and 5.08 l/ha respectively. In the wet campaign, the quantities of herbicides and pesticides used are respectively 23 liters and 52 liters, of which the gross treatment dose is 1.28 l/ha for

Table 6. Situation of gross input doses used by producers.

Amount	NPK (kg)	Urea (kg)	OF (kg)	Herbicide (L)	Pesticide (L)
Dry Countryside	8400	4700	46,930	28	91
Dosage/ha CS	468.52	262.15	2731.78	1.56	5.08
Wet Countryside	6500	2850	9490	23	52
Rate/ha CH	362.54	158.96	529.31	1.28	2.90
Total	14,900	7550	56,420	51	143
Gross dose/ha/year	415.53	201.55	1573.43	1.42	3.99

Source: field survey.

herbicides and 2.90 l/ha for pesticides. The phytosanitary products that producers buy is rarely approved and some, intended for cotton, are used for the protection of market garden crops with Lamda super (lambda-cyhalothrin 25 g/L) which is the most widely used.

3.4. CO_2 Emissions from Inputs and Irrigation Equipment

The results of calculated CO_2 emissions from agricultural inputs and equipment show that NPK emits approximately 14734.50 kg CO_2eq in a year of production along the river. Urea has an emission of 17398.81 kg CO_2eq and pesticides 71.99 kg CO_2eq against 8.95 kg CO_2eq emitted by herbicides; *i.e.* a total of 80.94 kg CO_2eq.

As for the motor pumps, they emit more than 190222.4 kg CO_2eq. The results show that more than 222,437 kg CO_2eq are emitted by the use of motor pumps and inputs (mineral fertilizers and phytosanitary products). The use of inputs puts about 14.48% CO_2eq against 84.52% CO_2eq by the use of motor pumps.

The results of the variance analysis of emissions (Table 7) show a significant difference between the area exploited and the number of motor pumps. The high number of motor pumps (46) is the main source of CO_2 emissions into the atmosphere, especially those that run on butane gas.

3.5. Land Degradation

The structural stability (St) established through the Pieri index on the depth 0 - 30 cm gives a value of 0.98% for the left bank, 1.75% for the right bank and 2.33% for the thalweg (Table 8). All these values are less than 5%, indicating a 0 - 30 cm unstructured horizon with great sensitivity to erosion.

Table 7. Analysis of variance of CO_2 emissions.

Source	SS	F	MS	F	Prob > F	Meaning
SE * CO_2_emitted_CS	9.16×10^8	15	6.1×10^8	3.30	0.0309	S
SE * CO_2_emitted_CH	1.09×10^9	20	5.45×10^8	24.08	0.0011	HS
SE * CO_2_emitted_motor Pump	1.85×10^8	3	6.17×10^8	1.48	0.2465	NS
Age * CO_2_emitted_motor Pump	41.5	6	6.91	0.38	0.8422	NS
CO_2_emitted_motor Pump * NMP	3.78×10^9	5	7.56×10^9	5734.02	0.0002	HS

CS: Dry Season. CH: Rainfall Season. SE: Area Exploited. NMPs: Number of Motor Pumps in possession. S: Significant. HS: Highly Significant. NS: Not Significant SS: Sum of Squares. DF: Degree of Freedom MS: Mean Square F: statistical variable.

Table 8. Land degradation risk index along the Bomboré River.

Morphopedological_unit	S_t (%)	Observations on S_t	I_c (%)	Observations on I_c
Left Bank	0.98	Unstructured Horizon, Great Sensitivity to Erosion	0.83	Low Risk of Deterioration
Right Bank	1.75	Unstructured Horizon, Great Sensitivity to Erosion	1.57	Medium Downside Risk
Talweg	2.33	Unstructured Horizon, Great Sensitivity to Erosion	0.85	Low Risk of Deterioration

The crusting index (I_c) of the left bank and the thalweg is 0.83 and 0.85 respectively. This I_c, which is less than 1.5, shows a low risk of deterioration of the horizon. The crusting index takes into account the leaching of the horizon, the crusting and the level of biological activity in the soil. As for the Ic of the right bank, it is 1.57 corresponding to an average risk of deterioration.

The erosivity (*R*) of rainfall, calculated on the basis of rainfall data from Mogtédo gives a value of 397.22 MJ·mm·ha^{-1}h^{-1}·year^{-1}. The erodibility calculation gives an average value of 0.408 th ha/ha·MJ·mm on the vertisol with hydromorphic external drainage.

The incidence of the slope (*LS*) length and its inclination of the calculated study area varies between 0 and 3.12. Its average value is 0.11. Plant cover (*C*) of the study area is very low with an average cover value of 0.375. The area is not developed and the presence of ridges as irrigation networks represents 66.84%. The average cultural practices (*P*) along the river are 0.27.

The soil loss map is thus established by multiplying the different factors of the Revised Universal Soil Loss Equation (RUSLE). In the right-of-way of the study site, the annual loss of land is estimated at 481.22 t/ha/year with an average rate of 2.30 t/ha/year. On the area of 209.23 ha of the study site, 58.93% of the area has a water erosion rate of less than 01 t/ha/year. The highest erosion potential (20 - 44.17 t/ha/year) covers an area of 1.90 ha or 0.91% of the study area (Figure 2 and Table 9).

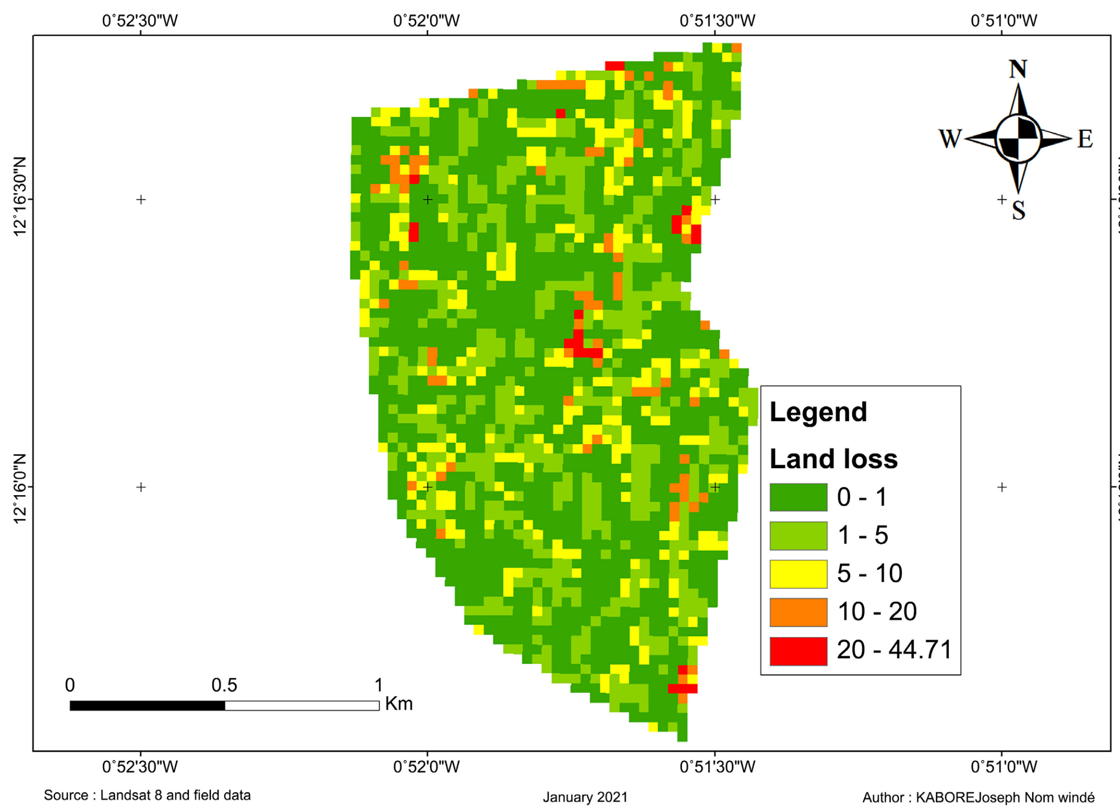

Figure 2. Potential for soil loss along the Bomboré River.

Table 9. Distribution of soil losses along the Bomboré River.

Soil Erosion Risk Class	Land Loss Rate (t/ha/year)	Area (ha)	Percentage (%)
Very Weak	0 - 1	123.29	58.93
Weak	1 - 5	51.63	24.68
AVERAGE	5 - 10	25.17	12.03
Moderate	10 - 20	7.24	3.46
Raised	20 - 44.17	1.90	0.91

4. Discussions

This study shows that agricultural production systems using irrigation along the Bomboré River present various risks of agricultural land degradation. The lack of development of the lowlands coupled with water wastage (watering can and furrow irrigation) lead to sheet erosion of the soil on the scale of the irrigated plots. This situation was already observed along the Mouhoun Rivers in Burkina Faso [37].

Lack of knowledge of the technical characteristics of motor pumps (Total Manometric Head (HMT), Net Positive Suction Head (NPSHr)) and the inability of producers to determine water needs by speculation practiced (tomato, cabbage, amaranth, eggplant, etc.) causes an uncontrolled flow of irrigation water and therefore accelerates sheet erosion. This poor organization of producers is due to the rapid drying up of the river (month of February), from which each producer has the ambition to save his production.

The use of motor pumps for irrigation has led to the deployment of PVC pipes on the most distant plots up to those which are almost in the minor bed of the river. The cumulative length of the pipelines on either side of the banks of the river is 6.8 km.

The excesses of mineral fertilizers observed for NPK (362.5 kg) and urea (158.96 kg) in the plots are detrimental to the quality of surface and groundwater but also promote the eutrophication of farmland. The excess inputs in market gardening lead to dietary imbalances for leafy vegetable consumers [26]. The excessive use of mineral fertilizers could also lead to acidification of the soil and this justifies the current water pH of vertisols in the study area found to be around 5.56. Several studies [38] [39] [40] have come to the same conclusion that the use of high doses of mineral fertilizers destabilizes soil structures and also contributes to its acidification. The consequence of eutrophication is a transfer and deposit of excess nutrients and phytosanitary products in wetlands, resulting in an ecological imbalance due to colonization of plants [41]. This justifies the invasive presence of aquatic plants such as *Typha domingensis* Pers., *Eichhornia crassipes* (Mart.) Solms *or water hyacinth*, *Cyperus articulatus* L., *Mimosa pigra* Linn. and *Azolla africa* Desv., observed in the Bomboré River bed. The phytosanitary products used for market gardening (crotal, Lamda super K, etc.) are not approved and unsuitable for sown crops (tomato, onion, lettuce, eggplant, amaranth). The xcessive use of pesticides pollutes soils and water. The active ingredient of these phytosanitary products is persistent in the soil with a leaching potential that ranges from low to high [42]. Another difficulty related to excessive use of pesticides along the Bomboré River would be the resistance that insects and weeds could develop [43].

The resistance of plants and insects to phytosanitary products is linked to the specific nature of the herbicides and/or pesticides but also to the application modes [42]. It would be better to make producers aware of the adoption of good agricultural practices, safe protection measures in the use of pesticides so that they change their behaviors [44]. The use of biological pesticides and bio-aggressors could constitute an alternative for the implementation of ecological intensification models for market gardening.

Agricultural activities carried out along the Bomboré River emitted more than 222436.66 kg CO_2eq in one agricultural campaign. This could be explained by an intensive use of pesticides to deal with the attacks of pests and diseases, hence an increase in the active ingredient of phytosanitary products.

The ratio of 02 motor pumps per producer shows that the motor pumps operate continuously and would therefore release more CO_2 into the atmosphere. The use of motor pumps older than 5 years could thus be the basis of the high CO_2 emission; the latter being assumed to be amortized. To achieve the ambition of reducing its CO_2 emissions by 29.42%, *i.e.* 31632.85 Gg CO_2eq set by Burkina Faso (NDC, 2021), it would be appropriate to popularize clean energy and not pollutants pumping equipment.

The indices of sensitivity to degradation (S_t and I_c) of the vertisol along the Bomboré River reflect the level of stability of the aggregates. They show the level of balance between clay, organic matter and silt at a depth of 30 centimeters in the ground. The destructuring of the surface horizons of the study area (S_t between 0.98% and 2.33%) is favored on the one hand by the formation of settling crusts and on the other hand by acidification of the soil. and low organic matter content. Acid soils are particularly sensitive to leaching which, carrying away Ca^{2+} and Mg^{2+} ions, decreases the base saturation rate, and further aggravate acidification [45].

The low rate of organic matter would be the basis of the average risk of soil degradation on the right bank. The index of hydraulic and pedological functioning of the irrigated perimeter of Gouran in the Sourou valley in Burkina has confirmed [46]. The destruction of the rupicolous and the banks of the river by the operators would have contributed to accentuating soil degradation on the right bank. The heavy use of mineral fertilizers weakens the soil structure and exposes it to water erosion [40].

Excessive use of chemical fertilizers coupled with poor agricultural practices would physically degrade soil organic matter resulting in weak interaction between soil organic carbon and structural aggregates.

An input of organic manure up to a maximum of 5 t/ha every 2 years is sufficient to maintain soil fertility [40].

Along the Bomboré River, the average rate of land loss would be linked to poor farming practices by producers, such as plowing plots according to water flow direction and making irrigation furrows. In addition, the presence of a gold panning site in the watershed with discharge of artisanal gold leaching water into the watercourse, contributes to accelerating land erosion; thus excavation and carry away of lands into the river.

The results of soil degradation along the Bomboré River are similar to those of the authors which showed a soil loss of 2.32 t/ha/year downstream of small dams in the Nakanbé basin [8]. In the commune of Karangasso vigué in Burkina Faso, land loss values are between 0 to 1.57 t/ha/year corresponding to 97.92% of the communal territory [47]. The average land loss rate is 1.22 t/ha/year in the upper Sissili watershed in Burkina Faso using the RUSLE model [29].

The spontaneous settlements around the study area upstream of the river would also be a source of tortuosity in the flow axes contributing to increase runoff speed and land erosion in the study area.

To curb land degradation along the Bomboré River, it would be important to:

- Develop producers' capacities in land management using proven methods.
- Take sustainable actions on river bank restoration with producers' implications.
- As well as promoting ecological agriculture practices on their farmlands.

5. Conclusions

This study on agricultural activities along the Bomboré River in the Nakanbé-Bomboré sub-watershed is part of a reflection on the analysis of the impact of agricultural activities on land degradation. The objective was to assess the level of farmlands degradation along the Bomboré River as a result of agricultural activities. The study results show that producers excessively use mineral fertilizers and phytosanitary products which contribute to accelerating land degradation along the river. These excessive uses of fertilizers combined with the use of defective moto pumps are sources of considerable CO_2 emissions into the atmosphere. Agricultural practices carried out by producers are an additional source of soil and water degradation with acidification and eutrophication of the river. Areas with low vulnerability to erosion cover 83.61% of the study area, those with medium vulnerability represent 15.49% and those with high vulnerability represent 0.91%. The results show that lands along the Bomboré River are not subject to intensive erosion.

This study calls for more vigilance and monitoring actions to sustainably safeguard basic production resources (land and water) for food security to 73,214 inhabitants of the municipality.

Authors' Contribution

KJN, SSEG, SWJP, SB and ORC carried out the study and participated in the data processing. They participated in the design of the research study project and supervised the work. All these authors contributed to the writing of the manuscript submitted to your journal for publication

Conflicts of Interest

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

References

[1] Ministère de l'Agriculture des Aménagements Hydroagricoles et de la Mécanisation (2020) Rapport Annuel de Performance.

[2] Ministère de l'Agriculture des Ressources Animales et Halieutiques (2022) Plan Stratégique National D'investissement Agro-Sylvo-Pastoral (2021-2025).

[3] Ministère de l'agriculture et des aménagements hydrauliques (2017) Deuxième Programme National du Secteur Rural (PNSR) 2016-2020.

[4] Thiombiano, L. (1997) Les bas-fonds du Burkina-Faso: Contraintes et potentialités pour une mise en valeur durable. Acte Sémin. Natl. Bobo-Dioulasso.

[5] Kambou, D. (2019) Évaluation des Performances Techniques de l'Irrigation au Burkina Faso. University of Liège—Gembloux Agro-Bio Tech.

[6] Ouédraogo, R.A., Kambiré, F.C., Kestemont, M.-P. and Bielders, C.L. (2019) Caractériser la diversité des exploitations maraîchères de la région de Bobo-Dioulasso (Burkina Faso) pour faciliter leur transition agro-écologique. *Cahiers Agricultures*, **28**, Article No. 20. https://doi.org/10.1051/cagri/2019021

[7] Ouattara, Y., Guiguemde, I., Diendere, F., Diarra, J. and Bary, A. (2012) Pollution des eaux dans le bassin du Nakambé: Cas du barrage de Ziga. *International Journal of Biological and Chemical Sciences*, **6**, 8034-8050. https://doi.org/10.4314/ijbcs.v6i6.47

[8] Guyon, F., Hallot, E., Kima, E. and De Thysebaert, D. (2014) Estimation de la sédimentation des retenues hydro-agricoles de Kierma et de Wedbila. Présenté à 1ères Journées Scientifiques et Techniques de l'Agriculture Irriguée, Ouagadougou.

[9] Koné, M., Bonou, L., Bouvet, Y., *et al.* (2009) Etude de la pollution des eaux par les intrants agricoles: Cas de cinq zones d'agriculture intensive du Burkina Faso. *Sud Sciences et Technologies*, **17**, 6-15.

[10] Compaore, H., Sauret, É., Kissou, O., Kinglo, M., Bazongo, P., Yameogo, P., Koita, M. and Serme, I. (2022) Use of Multi-Method Approach for a Gravity Irrigation Network Diagnosis: Case of Karfiguela Paddy Field in Burkina Faso. *Agricultural Sciences*, **13**, 1396-1420.

[11] Kinglo, A.M.A., Sauret, E., Koïta, M., *et al.* (2022) Multi-Approach Characterization of Groundwater for Irrigated Agriculture in Southwest Burkina Faso. *Groundwater for Sustainable Development*, **20**, Article ID: 100867. https://doi.org/10.1016/j.gsd.2022.100867

[12] Hallot, E., Guyon, F., De Thysebaert, D. and Diarra, B.G. (2019) Gestion intégrée des petites retenues hydro-agricoles au Burkina Faso. Geo-Eco-Trop.

[13] Karambiri, H., Hamma, Y., Barbier, B., *et al.* (2009) Caractérisation du ruissellement et de l'érosion de la parcelle au bassin versant en zone sahélienne: Cas du petit bassin versant de Tougou au nord du Burkina Faso. Improving Integrated Surface and Groundwater Resources Management in a Vulnerable and Changing World. *Pro-*

ceedings of JS.3 at the Joint IAHS & IAH Convention, Hyderabad, September 2009, 330 p.

[14] Sauret, E. (2008) Contribution à la compréhension du fonctionnement hydrogéologique du système aquifère dans le bassin du Kou. Mémoire de Fin d'Etude de Diplôme d'Etudes Approfondies (DEA) en Sciences Appliquées, Option Géologie et Science de l'Environnement, Université de Liège, Liège, 96 p.

[15] Bambara, A. (2021) Caractérisation et modélisation des nappes d'eau souterraine au voisinage de petites retenues d'eau d'irrigation en zone de socle: Cas de kierma et de Mogtédo (Burkina Faso). Doctorat en Sciences de l'Ingénieur, Université de Liège, Liège, 291 p.

[16] Sauret, E. (2013) Etude des potentialités hydrogéologiques d'une plaine alluviale en relation avec les eaux souterraines et de surface dans un contexte d'agriculture irriguée (Burkina Faso). Doctorat en Sciences de l'Ingénieur, Université de Liège, Liège, 215 p.

[17] Traoré, F. (2021) Optimisation de l'utilisation des ressources en eau du bassin du Kou pour des usages agricoles. Doctorat en Sciences, Université de Liège, Liège, 195 p.

[18] Peeters, A. (year) Apports de la géomorphologie dans les processus de conception, de suivi et d'évaluation de projets de restauration de cours d'eau à différentes échelles spatiales et temporelles. Doctorat en Sciences, Université de Liège, Liège, 254 p.

[19] Ouédraogo, R.A. (2019) Impact des pratiques de gestion de la fertilité sur la qualité des sols sous cultures maraîchères à Bobo-Dioulasso (Burkina Faso). Doctorat en Sciences Agronomiques et Ingénierie Biologique, Université Catholique de Louvain, Belgique, 207 p.

[20] Direction Générale des Ressources en Eau (2008) Définition d'un schéma de couverture spatiale des comités locaux de l'eau dans les bassins versants nationaux: Cas du bassin national du Nakanbé.

[21] Killian, J. (1972) Méthodes d'investigation pour l'analyse et le classement des bas-fonds dans quelques régions de l'Afrique de l'Ouest. Proposition de classification d'aptitude des terres à la riziculture. *L'Agronomie Tropicale*, **282**, 156-172.

[22] Ayers, R.S. and Westcot, D.W. (1976) Bulletin FAO d'Irrigation et de Drainage, 29. La Qualité de l'Eau en Agriculture.

[23] CPCS (1967) Classification des Sols. Publication of Ensa-Grignon, Paris.

[24] Gaillard (1997) Inventaire environnemental des intrants agricoles en production végétale. Comptes Rendus de la FAT.

[25] FAO (2015) Estimations des émissions de gaz à effet de serre en agriculture. Un Manuel pour Répondre aux Exigences de Données des Pays en Développement.

[26] FAO (2015) La gestion durable des sols: Clé pour la sécurité alimentaire et la nutrition en Afrique. *Revu Nature & Faune*, **30**, 123 p.

[27] Pieri, C. (1989) Fertilité des terres de savanes. Bilan de trente ans de recherche et de développement agricoles au sud du Sahara. Ministère de la coopération et du développement. Ministère de la Coopération et du Développement, Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Paris.

[28] FAO (1994) Directives pour la description des sols. 3ème Édition (Revisée), Service des Sols-Ressources, Aménagement et Conservation. Division de la Mise en Valeur des Terres et des Eaux.

[29] Yaméogo, A., Somé, Y.S.C., Palé, S., *et al.* (2021) Application de SIG/RUSLE à l'estimation de l'érosion par ruissellement en nappe dans le bassin versant supérieur de la Sissili (Burkina Faso). *Geo-Eco-Trop*, **45**, 299-310.

[30] Renard, K.G. and Freimund, J.R. (1994) Using Monthly Precipitation Data to Estimate the R Factor in the Revised USLE. *Journal of Hydrology*, **157**, 287-306. https://doi.org/10.1016/0022-1694(94)90110-4

[31] Wischmeier, W.H. and Smith, D.D. (1978) Predicting Rainfall Erosion Losses—A Guide to Conservation Planning. Agriculture Handbook No. 537. Department of Agriculture, Science and Education Administration.

[32] Roose, E. and De Noni, G. (2004) Recherches sur l'érosion hydrique en Afrique: Revue et perspectives. *Science et Changements Planétaires/Sécheresse*, **15**, 121-129.

[33] 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**. https://doi.org/10.4000/vertigo.12591

[34] Roose, E. (1994) Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols (GCES), Vol. 70. Organisation des Nations Unies pour l'alimentation et l'agriculture.

[35] Hussein, H., Laurence, C. and Laurent, T. (2018) Modélisation de l'érosion hydrique à l'échelle du bassin versant du Mhaydssé, Békaa-Liban. *VertigO: La Revue Électronique en Sciences de l'Environnement*, **18**. http://journals.openedition.org/vertigo/19804 https://doi.org/10.4000/vertigo.19804

[36] Toumi, S., Meddi, M., Mahé, G. and Brou, Y.T. (2013) Cartographie de l'érosion dans le bassin versant de l'Oued Mina en Algérie par télédétection et SIG. *Hydrological Sciences Journal*, **58**, 1542-1558. https://doi.org/10.1080/02626667.2013.824088

[37] Dianou, D., Savadogo, B., Zongo, D., *et al.* (2011) Qualité des eaux de surface dans la vallée du Sourou: Cas des rivières Mouhoun, Sourou, Debe et Gana au Burkina Faso. *International Journal of Biological and Chemical Sciences*, **54**, 1571-1589. https://doi.org/10.4314/ijbcs.v5i4.22

[38] Kpadenou, C.C., Tama, C. and Yabi, J.A. (2019) Déterminants des investissements des maraîchers dans la gestion intégrée de la fertilité des sols et des ravageurs dans la vallée du Niger au Bénin. *European Scientific Journal*, **15**, 117-134. https://doi.org/10.19044/esj.2019.v15n33p117

[39] Ognalaga, M., Boussiengui-Boussiengui, G. and Oyanadigui Odjogui, P.I. (2015) Contribution à la restauration de la fertilité des sols du périmètre maraîcher de l'IGAD DJAMITI (Franceville) par l'apport raisonné des amendements organiques et minéral. *Journal of Animal and Plant Sciences*, **24**, 3843-3853.

[40] Ouandaogo, N., Ouattara, B., Pouya, M.B., *et al.* (2016) Effets des fumures organo-minérales et des rotations culturales sur la qualité des sols. *International Journal of Biological and Chemical Sciences* **102**, 904-918. https://doi.org/10.4314/ijbcs.v10i2.37

[41] Gomgnimbou, A.P.K., Savadogo, P.W., Nianogo, A.J. and Millogo, J.R. (2009) Usage des intrants chimiques dans un agrosystème tropical: Diagnostic du risque de pollution environnementale dans la région cotonnière de l'est du Burkina Faso. *Biotechnologie, Agronomie, Société et Environnement*, **13**, 499-507.

[42] Le Bars, M., Sidibé, F., Mandart, E., *et al.* (2020) Évaluation des risques liés à l'utilisation de pesticides en culture cotonnière au Mali. *Cahiers Agricultures*, **29**, Article No. 4. https://doi.org/10.1051/cagri/2020005

[43] Son, D., Somda, I., Legreve, A. and Schiffers, B. (2017) Pratiques phytosanitaires des producteurs de tomates du Burkina Faso et risques pour la santé et l'environnement.

Cahiers Agricultures, **26**, Article No. 25005. https://doi.org/10.1051/cagri/2017010

[44] Brévault, T., Badiane, D., Goebel, R., *et al.* (2019) Repenser la gestion des ravageurs du cotonnier en Afrique de l 'Ouest. *Cahiers Agricultures*, **28**, Article No. 25. https://doi.org/10.1051/cagri/2019024

[45] Ilboudo, A. (2020) Dynamique de dégradation des bas-fonds soudano-sahéliens dans un contexte de changement climatique: Cas des bas-fonds du sous bassin versant Nakanbé-Dem.

[46] Adjeffa, E. (2015) Incidence du fonctionnement hydraulique et pédologique des périmètres irrigués sur la production agricole: Cas du périmètre irrigué de Gouran dans la vallée du Sourou au Burkina Faso. 2ie, Burkina Faso.

[47] Ouédraogo, B., Kabore, O. and Kabore, M. (2019) Cartographie quantitative de l'érosion des sols par approche SIG/RUSLE dans la Commune de Karangasso vigué (Burkina Faso). *International Journal of Biological and Chemical Sciences*, **133**, 1638-1653. https://doi.org/10.4314/ijbcs.v13i3.35