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Impacts of Anthropogenic Activities on the Quality of Dam Lakes in Northern Côte d'Ivoire: The Case of the Korhogo, Boundiali and Katiola Dams

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Abstract

The objective of this study is to assess the effect of human activities on the quality of dam waters with a view to sustainable resource management. The processing of Landsat 7 satellite images using ENVI 5.1 software has been used to develop land use mapping and to assess human activities in dams' watersheds. The rate of change and the annual rate of change were used to characterize the dynamics of land use (OCS). Sampling and analysis campaigns were carried out to assess water quality through the use of the Water Quality Index (WQI). Results show that areas occupied by natural spaces in 2000, on all dams' watersheds with 59.26%, were reduced in favor of humanized areas in 2024 (77.44% of the total area). These anthropized areas are dominated by agricultural activities with 53.46%, followed by buildings and bare soils (23.23%). In addition, the level of anthropization of dams watersheds are respectively 96.23% in Korhogo, 83.06% in Katiola and 53.04% in Boundiali. The IQE assessment indicates that the overall water quality is poor for all the dams with IQE index = 28 for Korhogo, IQE index = 37 for Katiola and IQE index = 42 for Boundiali. During rainy season, water quality is poor for all dams. However, during dry season, the dams are divided into two quality classes. Poor water quality is found at Korhogo and Katiola dams, while Boundiali dam is in mediocre quality class. The content of COD, BOD, Fe, Mn, Pb, As, Hg, and pesticides have been identified as parameters responsible for water pollution.

The implementation of integrated management strategies for different watersheds could reverse the adverse effects of human activities on water quality.

Keywords

Land Use, Human Activities, Pollution, Dam Water

1. Introduction

Access to fresh water, in sufficient quantity and quality, is essential for all aspects of life and for sustainable development [1]. Indeed, fresh water is a precious resource indispensable for human health, food and energy security, poverty eradication and many other aspects of sustainable development. However, its availability in quality and quantity is a major concern for countries that must meet their increasingly growing needs for economic development [2]. Indeed, since the 1950s, the Earth's climate has undergone changes represented, essentially by warming due to greenhouse gases, in close relation with human activity [3]. Global changes, especially climate change, changes in land use and the intensification of human activities, have modified hydrological dynamics and quality of freshwater resources on a global scale [4] [5]. This situation has increased the imbalance between water resources and uses, particularly for drinking water. In many countries, dam reservoirs represent a strategic source of drinking water supply in a context of high climate variability and water stress. However, the quality of water stored in these reservoirs is increasingly compromised by the intensification of anthropogenic pressures such as unplanned urbanization, extensive agricultural activities, domestic and industrial discharges, as well as deforestation [6]-[8]. The dam reservoirs of Côte d'Ivoire, particularly those located in the northern part, are not spared the effects of global changes. Indeed, since their commissioning in the 1990s, they have been subject to the exacerbated effects of global warming and anthropogenic pressures. These effects seriously compromise the potability of water from the reservoirs, making treatment more complex and costly, and even ineffective in certain situations [9]. Although these dams play a crucial socioeconomic role, few studies have focused on assessing the physicochemical quality of their waters in relation to anthropogenic pressures, particularly land use changes. This situation limits the understanding of the dynamics of dam water quality alteration and thus hinders the implementation of effective integrated water resource management strategies. This study therefore aims to assess the effect of land use dynamics in the supply watersheds on the quality of reservoir waters.

2. Materials and Methods

2.1. Material

2.1.1. Presentation of the Study Area

The study area is located in the northern part of Côte d'Ivoire beyond 8˚ North latitude with eleven regions Bounkani, Gontoungo, Tchologo, Hambol, Bere, Poro, Bagoue, Woroddougou, Kabadougou, Folon and Bafing. The area covers approximately 37% of Ivorian national territory. For this study, only dams in the Katiola, Korhogo and Séguela are concerned. Figure 1 shows the geographical location of the three dams in this study.

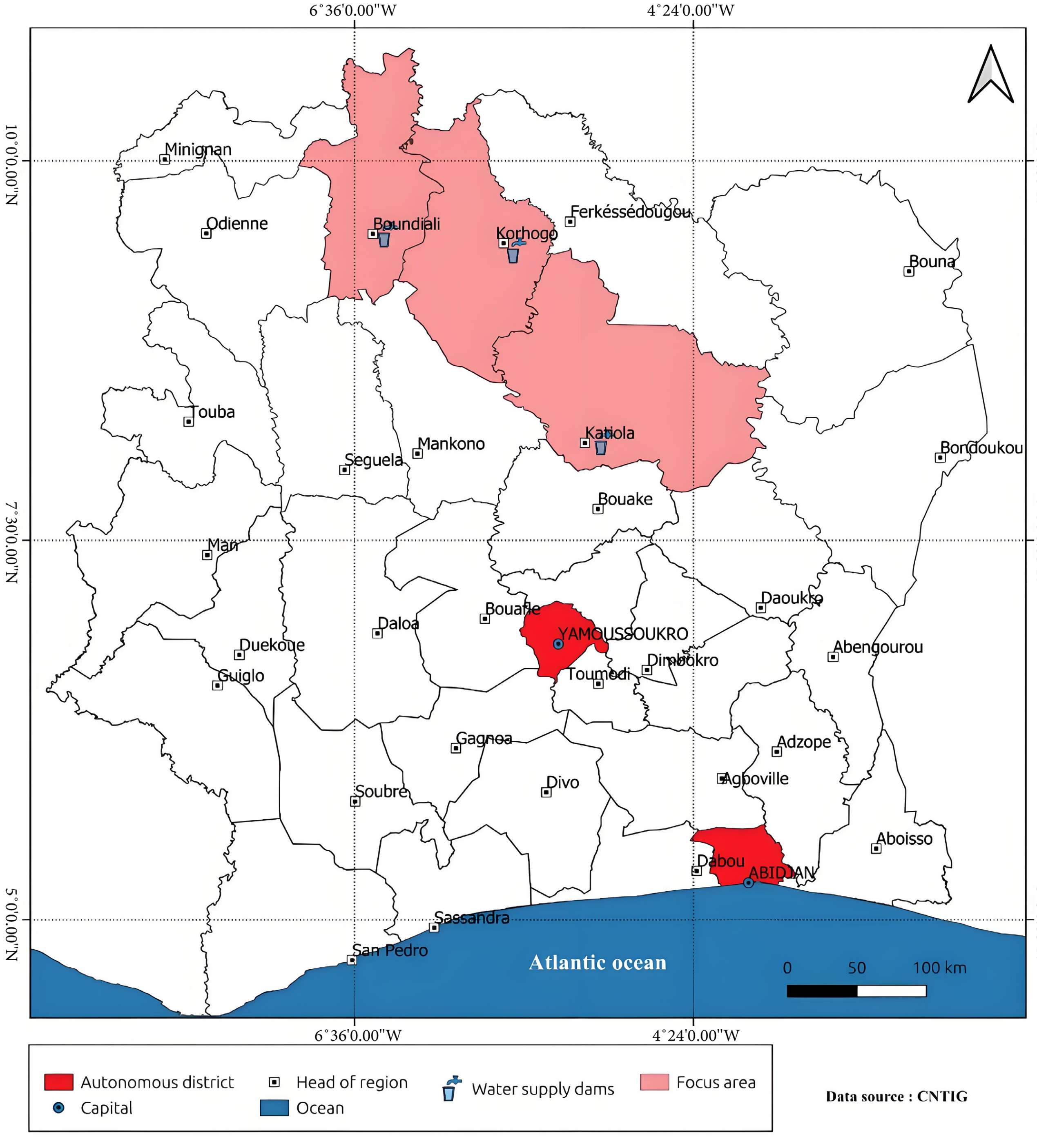

Figure 1. Presentation of the study area.

2.1.2. Data Used

The data used consist of Landsat images, notably Landsat 7 ETM+ from the year

2000 and Landsat 8 OLI from the year 2024 with 30 m spatial resolution (Table 1). They were used to produce land use maps.

Table 1. Data summary.

Data Types	Data	Resolution	Sources
	MNT	30 × 30 m	https://www.usgs.gov/products/maps/overview
	Land use	30 m	http://earthexplorer,usgs.gov.

2.2. Methods

To achieve the objectives of this study, land use has been characterized and impacts of human activities have been evaluated on dam waters.

2.2.1. Spatio-Temporal Distribution of Anthropogenic Activities in Dam Watersheds

Figure 2 shows the diagram for making maps of different land uses for years 2000, and 2024.

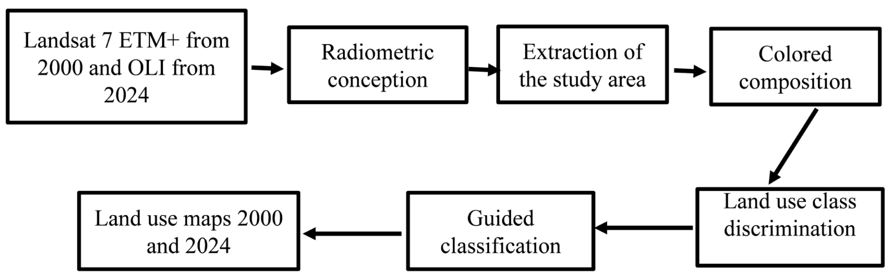

Figure 2. Steps for producing land use maps for 2000 and 2024.

2.2.2. Identification of Anthropogenic Activities in Dam Watersheds

The inventory of human activities in watersheds of the various dams was carried out by combining results of land use maps and those of the field survey. This survey has been done from January 2022 to December 2023. It consisted of making direct observations and discussing with the various users.

2.2.3. Analysis of dam water

1) Sampling

Two sampling campaigns were carried out between 2021 and 2022 during dry and rainy seasons. Samples were taken at two key points of different dams: different inlets and dikes for each dam (Figure 3).

2) Analysis Methods

pH, temperature, electrical conductivity, and dissolved oxygen were measured *in situ* using respectively a HANNA HI 99101 pH meter, a WTW MULTI 3332 conductivity meter, and a Sanxin 8X716 oximeter. Samples were then placed in polyethylene bottles, transported in a cooler at 4˚C, and processed in the laboratory within 24 hours. Analyses of other parameters were performed in the laboratory. Table 2 shows methods used for water analyses.

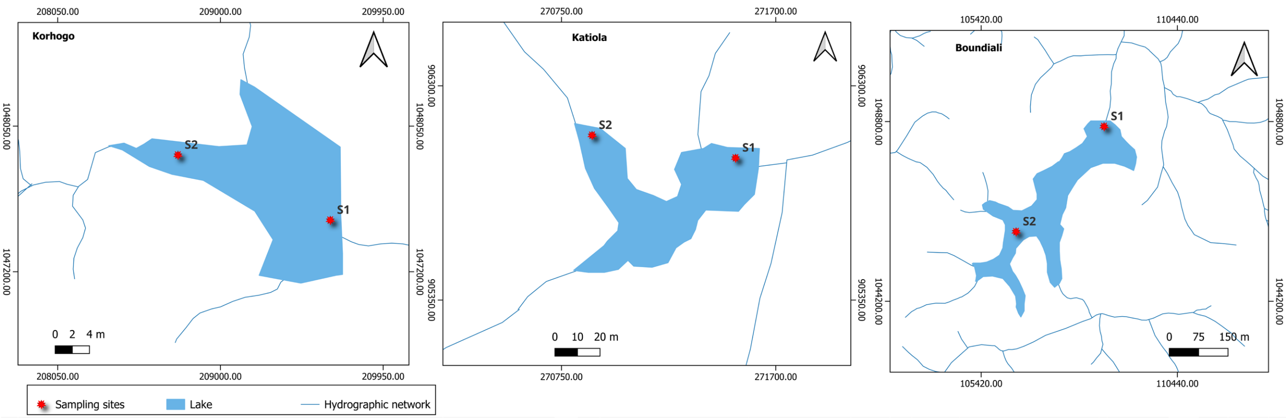

Figure 3. Sampling key points at drinking water supply dams: Korhogo, Katiola and Boundiali.

Table 2. Parameter analysis methods.

Parameters	Methods
pH	ISO 10523 V 2008
Turbidity	ISO 10523 V 2008
Temperature	Pt 100
Conductivity	ISO 7888 V 1985
Dissolved oxygen	ISO 5814 V 2012
DCO	Closed tubes
DBO_5	Respirometric
Nitrates	ISO 7890-3 V 1988
Nitrites	Diazotization
Total cyanides	Pyrazolone-pyrine
Dissolved Iron (Fe)	700 (Flame)
Total manganese (Mn)	ISO 15586 V 2003
Arsenic (As)	ISO 17378-2 V 2014
Lead (Pb)	ISO 8288 V 1986
Mercury (Hg)	ISO 12846 V 2012
Ammonium (NH_4^+)	NF T 90-015-2 V 2000
Total phosphorus (PO_3^{4-})	ISO 6878 V 2004
Organohalogen pesticides	IN NF ISO 6468-97
Organophosphate pesticides	EN NF ISO V 11369-97
Carbonate Pesticides	EN NF ISO V 11369-97

2.3. Assessment of the Quality of Dam Water

Evaluation of the Water Quality Index of Dams

Several indices are used to assess the quality of dam water, including the arithmetic weighted index (IAPQE) and CCME water quality index (IQE-CCME). These indices have been used in several studies [10]-[14]. CCME Water Quality Index (CCME-WQI) has been widely adopted worldwide, and is distinguished by its flexibility and absence of manual weighting of parameters. It has been adopted in several countries around the world such as Turkey, India, Chile, Iran, Indonesia and Romania for water quality assessment [15]-[18]. Organic Pollution Index (OPI) has used to assess the pollutant load. Eighteen major parameters were taken into account, including pH, COD, nitrates, heavy metals and pesticides. The maximum concentrations were compared with those in the Official Journal of the French Republic [19], the Ivorian standard being incomplete. The study took place during the dry and rainy seasons of 2021 and 2022.

1) Calculation of CCME Water Quality Indices (CCME WQI)

The CCME WQI consists of three components: extent (F1), the number of water quality variables that do not meet the water quality objective; frequency (F2), the number of times the objectives are not met; and magnitude (F3), the degree to which the objectives are not met. The CCME WQI is calculated using equation (3). In this study, the first factor was modified to account for the frequency of samples with exceedances of quality criteria to balance the factor F1. Indeed, studies conducted by Mercier *et al* 2004 and 2005 demonstrated the existence of a bias resulting from the use of the current formula of F1, therefore the use of modified form in our study. The CCME WQI equations are as follows [20] [21]:

- **Factor 1:** Scope

$$\mathrm{F}_{1\text{modifie}} = \mathrm{F}_{1\mathrm{a}} + \mathrm{F}_{2\mathrm{b}} \tag{1}$$

$$\mathrm{F}_{1\mathrm{a}} = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)\times 100 \tag{2}$$

$$\mathrm{F}_{1\mathrm{b}} = \left(\frac{\text{Number of non-compliant samples}}{\text{Total number of samples}}\right)\times 100 \tag{3}$$

- **Factor 2:** Frequency

$$\mathrm{F}_{2} = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right)\times 100 \tag{4}$$

- **Factor 3:** Amplitude

$$\mathrm{F}_{3} = \left(\frac{\text{nse}}{0.01\text{nse}+0.01}\right)\times 100 \tag{5}$$

$$\text{nse} = \left(\frac{\sum_{i=1}^{n}\text{excursion}_i}{\text{Total number of test}}\right)\times 100 \tag{6}$$

If the measured value (denoted Criterion Exceedance in the following equations) does not exceed the quality criterion:

$$\text{excursion}_\text{i} = \left(\frac{\text{Objective}_i}{\text{Failed Test Value}_i}\right) - 100 \tag{7}$$

If the measured value is not higher than the quality criterion, then the mathematical formula for calculating the CCME IQE value is:

$$IQE_{\text{CCME modified}} = 100 - \left(\frac{\sqrt{F_{1\text{modified}} + F_2 + F_3}}{1.712} \right) \quad (8)$$

The index results range from 0 to 100, ranging from the worst water quality to good water quality. Table 3 shows classification of quality classes according to the WQIs.

Table 3. Classification of surface water quality index (WQI) categories [21].

Class	WQI value	Water quality
Excellent	95 ≤ WQI < 100	Water quality is preserved, with virtually no threats or deterioration detected; conditions are very close to natural or desirable levels.
Good	80 ≤ WQI ≤ 94	Water quality is preserved, with only minor threat or deterioration observed; conditions rarely deviate from natural or desirable levels.
Average	65 ≤ WQI ≤ 79	Water quality is usually preserved, but is occasionally threatened or deteriorated; conditions sometimes deviate from natural or desirable levels.
Poor	45 ≤ WQI ≤ 64	Water quality is frequently threatened or deteriorated; conditions often deviate from natural or desirable levels.
Bad	0 ≤ WQI ≤ 44	Water quality is almost always threatened or deteriorated; conditions generally deviate from natural or desirable levels.

2) Calculation of the organic pollution index (OPI)

The organic pollution index (OPI) of dams was determined using the method proposed by [22]. The principle is to first divide the values of the polluting elements (ammonium, nitrate, BOD, and phosphates) into 05 classes after calculating the average of these three polluting elements from the values obtained during laboratory analyses. Then, determine the corresponding class number for each parameter using the average data proposed by Leclercq (Table 4). Finally, the overall organic pollution index of the dam water is obtained by performing an arithmetic average of the pollution classes of all the parameters.

Table 4. Grid of classes of the organic pollution index [22].

Classes	NH_4^+ (mg/l)	NH_3^+ (µg/l)	BOD5 (mg/l)	PO_4^{3-} (µg/l)	IPO	Organic Pollution
5	<0.1	5	<2	<15	4.6 - 5.0	**None**
4	0.1 - 0.9	6 - 10	2.1 - 5	16 - 75	4 - 4.5	**Weak**
3	1 - 2.4	11 - 50	5.1 - 10	76 - 250	3.0 - 3.9	**Moderate**
2	2.5 - 6	51 - 150	10.1 - 15	251 - 900	2.0 - 2.9	**Forte**
1	>6	>150	>15	<900	1.0 - 1.9	**Very strong**

3. Results and Discussion

3.1. Spatio-Temporal Distribution of Anthropogenic Activities in Dam Watersheds

3.1.1. Analysis of Thematic Accuracy of Products Cartographic

Table 5 shows for each class the average reliability level and the main confusions observed. Overall, results are similar with overall accuracies of 95.61%. and 94.05% then 98.56% and 99.04% finally 99.90% and 96.91% respectively in Korhogo, Boundiali and Katiola for the 2000 and 2024 images. The Kappa indices are almost perfect, ranging from 0.942 (2000), 0.954 (2014) to 0.926 (2024) for Korhogo, 0.979 (2000), 0.943 (2014) to 0.986 (2024) for Boundiali and from 0.998 (2000), 0.971 (2014) to 0.960 (2024). The overall accuracy values, as well as those of the Kappa coefficients, obtained respectively for the 2000 and 2024 images for each of the dam catchment areas, demonstrate the validity of the occupation maps generated. However, some land use classes showed minor confusions in all carried out treatments. With the exception of these situations, all other types of land are quite clearly differentiated. These results are corroborated by the work of [23] cited by [24] which showed that a land use study can be validated if the Kappa index is between 50% and 75%. These results are in accordance with those obtained in the studies on the Bonoumin and Gourou basins in Ivory Coast with Kappa indices ranging from 0.89 to 99% [25].

Table 5. Mapping performance of different basin classifications slopes of dams

	Korhogo		Boundiali		Katiola	
Years	2000	2024	2000	2024	2000	2024
Kappa	0.942	0.926	0.979	0.986	0.998	0.960
Overall details	95.61%	94.05%	98.56%	99.04%	99.90%	96.91%

3.1.2. Mapping of Land Use in Watersheds

Figure 4 presents the land use of the different catchment areas. The different maps highlight a strong anthropization of natural environments in the catchment areas of the Korhogo, Boundiali and Katiola dams between 2000 and 2024. In Korhogo dam catchment area, anthropized escapes areas increased from 56% in 2000 to 96.23% in 2024. In Boundiali, in 2000 natural spaces (85.2%) dominated by wooded savannahs (68.8%) and shrub savannahs (11.3%). However, in 2024 the trend is reversed with 53.3% occupation by humanized spaces composed of crops and fallows (35.4%) and perennial crops (17.6%). In Katiola dam watershed, there was a reduction in natural spaces (48.6%) in 2000 composed of wooded savannahs (47.8%) and water bodies (0.8%) to the detriment of human activities (80.6%) in 2024 dominated by annual crops and fallows and perennial crops (52.6% and 21.6%).

3.2. Identification of Human Activities in Dam Basins

Figure 5 shows proportions of natural and human-made areas across the three watersheds feeding the dams. Between 2000 and 2024, natural areas decreased from 33.68% to 15.10%, marking a sharp decline in favor of humanized areas. The latter increased from 48.6% to 72.12%, with a clear increase in buildings and bare soils. This dynamic reflects an intensification of human activities, particularly agricultural and urban. Research carried out in West Africa by [26] in the Tamou

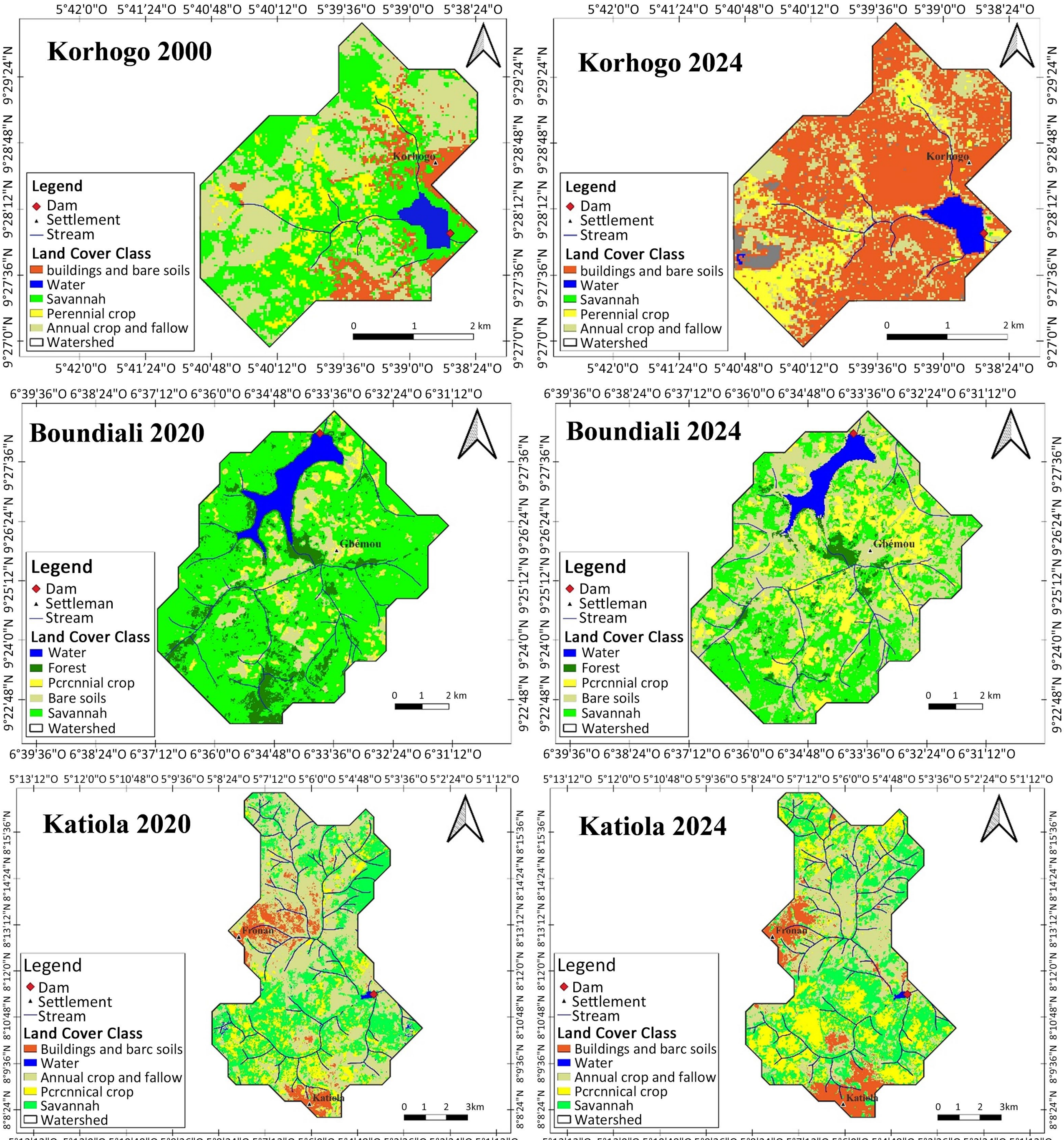

Figure 4. Dynamics of land use in dams of the Korhogo, Boundiali and Katiola (2000 and 2024).

Total Wildlife Reserve in Niger, [27] in the Tiogo classified forest in Burkina Faso confirms the trend observed in the present study. Similar results were obtained in Ivory Coast by authors such as [28] in the department of Séguéla, [29] in the department of Ferkessédougou or [30] in the sub-prefecture of Sinématiali. Indeed, all these authors observed in these different areas, a regression of vegetation in favor of anthropized areas. The reasons for this transformation of land use units in the dams watersheds are multiple. However, these changes could be attributed to three key factors resulting from the population explosion, namely the expansion of annual crops and fallow land, perennial crops and buildings. This situation could be explained by the conquest of natural space by human activities. Moreover, several elements influence the dynamics of land use in the area between 2000 and 2024, notably agricultural expansion and urbanization. Indeed, the areas of buildings and bare soil have increased fivefold, and those of perennial crops have doubled while those of annual crops and fallow land have increased by 10%. Perennial crops comprise of mango and cashew orchards. According to studies carried out by [30] producers in the region, the reasons for the expansion of perennial crops include marketing costs, soil suitability, fertilizer requirements and worker availability. Indeed, according to the results of this survey, the majority of farmers produce mango and cashew nuts because of their economic profitability, which is higher than food crops and cotton. Also, cotton production is very intensive in terms of inputs (fertilizers and pesticides), compare to cashew and mango orchards, which do not require the use of large quantities of fertilizers and phytosanitary products [31]. The same observations were made by [32] in the department of Katiola, where the development of cashew cultivation is materialized by an extension of production areas and a regression of food production areas. The authors [30] [33] [34] justified this attraction towards the production of cashew nuts by the increase in selling prices, which went from 0.15 US dollars/kg to 0.75 US dollars/kg between 1991 and 2017 and contributed enormously to the multiplication of cashew greenfinch areas. In addition to the factor of agricultural development, populations of these different cities have increased with that of Ivory Coast. Indeed, the Ivorian population has increased from 15,366,672 in 1998 to 29,389,150 peoples.

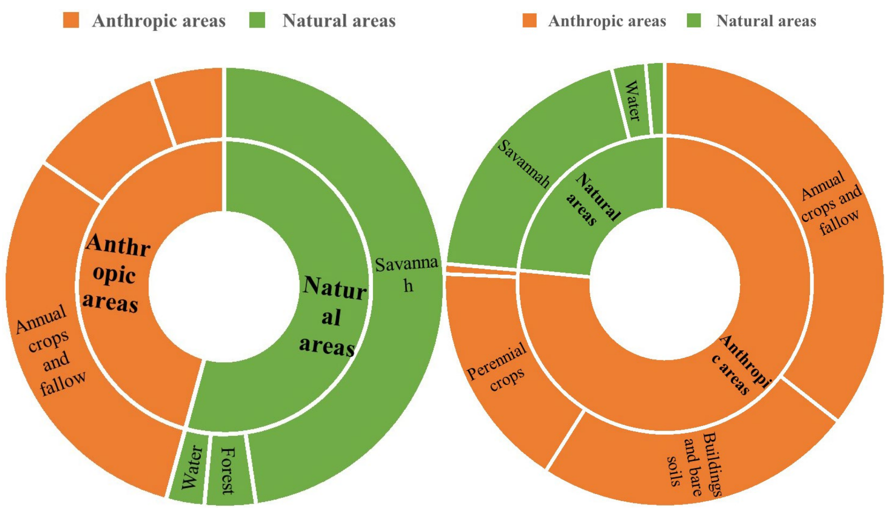

Figure 5. Summary of average land use in the three dams watersheds 2000 and 2024.

The field survey results highlighted anthropogenic activities on dams watersheds. **Table 6** indicates that main sources of the dams water pollution are linked to the geographical position of the dams. Indeed, Korhogo dam which is located in the city the main source of pollution remains the lack of sanitation followed by agricultural activities. Katiola dams located on the outskirts of this large city, the main source of pollution is agriculture followed by sanitation, while the main source of pollution remains agriculture at Boundiali dam, located in a rural area.

Table 6. Potential sources of pollution from dam water.

Land use classes	Potential source of pollution				
	Activities	Chemical parameters	Korhogo	Boundiali	Katiola
Buildings and bare soils	Wastewater/Solid waste	COD, BOD, heavy metals	60.81%	Very weak	9.67%
Perennial crops	Agriculture	Pesticides, heavy metals	10.76%	17.60%	21.55%
Annual crops and fallow	Agriculture	Pesticides, heavy metals	22.40%	35.45%	48.95%
Career	Mining gold/panning	Heavy metals	2.27%	Presence	Presence
Water	Farming/Breeding	Heavy metals/Pesticides	Yes	Yes	Yes

3.3. Quality of Dam Water

3.3.1. Water Quality Index (WQI_{CCME})

The average WQI values for the dams' water quality indices are 28.5, 37.4 and 42.2 respectively for Korhogo, Katiola and Boundiali, according to the graph in **Figure 6(A)**. This indicates that the water quality is poor for all dams. This could be explained by the human origin contamination showed in **Table 6**. Actually, urbanization and agriculture are the anthropogenic activities in the watershed. Pesticides and fertilizers, used in farming methods to reduce pests and increase yield, and heavy metals are main pollutants of the water of those dams. The presence of carbamates, organophosphates, and organohalogens showed by pesticides analyses support this finding.

The overall pesticide concentrations detected in the waters are 3.9 µg/l for Korhogo, 0.8 µg/l for Boundiali, and 0.7 µg/l for Katiola, according to the sums of the three most often used pesticides in the zone. These quantities are higher than the 0.5 µg/l Jorf raw water standards for all dams. Comparing to [35], these values are the same as those found in surface waters in several West African subregional countries as well as Côte d'Ivoire. Korhogo and Boundiali dams present the most polluted waters with highest pollution level.

Concerning heavy metals results for manganese, lead, mercury, and arsenic in dam water were higher than Jorf recommended levels. Iron and cyanide levels are below acceptable levels. In fact, the levels of arsenic in dam water vary with respect to Katiola (121.80 µg/L), Korhogo (96.54 µg/L), and Boundiali (45.8 µg/L). All of these concentrations are higher than the 10 µg/L JORF threshold for surface water meant for human consumption. Water from Katiola (9.30 µg/L), Korhogo (10.50 µg/L), and Boundiali (6.1 µg/L) dams had the highest lead concentrations. All of these values are higher than the JORF limits (5 µg/L) for surface waters intended for human consumption. The average levels of mercury Korhogo and Boundiali dams waters dams are respectively 1.77 µg/L and 1.01 µg/L. These values are higher than the standard of 1 µg/L. Regarding manganese, the values in the dams are, respectively, 0.61 mg/L at Boundiali, 0.33 mg/L at Korhogo, and 0.27 mg/L at Katiola. The observed values for all of these dams are higher than the JORF-permitted level of 0.1 mg/L for surface waters intended for human consumption.

Overall, all three dams contained mercury, lead, cyanides, arsenic, iron and manganese at different levels. Comparable results were also observed in three rivers in Côte d'Ivoire (Bandama, Comoé and Bia). Indeed, the work of [36] reveals the presence of significant heavy metals such as lead, arsenic and iron in these rivers. The same results were obtained in the Hiré area of Côte d'Ivoire by [37] in artisanal mining areas. These results demonstrate the presence of heavy metals in surface waters, but at levels lower than those found in this study. The presence of these metals in dam water could be explained by the degradation of dam watershed surfaces by anthropogenic activities. Indeed, according to [38]-[40], increasing urbanization, industrialization and the use of chemical fertilizers in agriculture are factors that contribute significantly to the pollution of surface waters by metal contaminants, through industrial discharges, urban drainage systems and runoff.

Seasonal variation in water quality in dams indicates a deteriorating trend during rainy season. Indeed, during rainy season, quality indices range from 25.3 in Korhogo to 40.4 in Tengrela, while during dry season, these values vary from 31.7 in Korhogo to 54.9 in Boundiali (**Figure 7(A)**). All dams are classified as poor quality during rainy season according to the CCME classification. During dry season, poor water quality is observed in Korhogo and Katiola dams, and mediocre water quality in Boundiali (**Figure 6(A))**. At the spatial level, the water quality is poor throughout the dams (**Figure 6(B)**). The levels of heavy metals and pesticides detected in dam waters are significantly higher during the rainy season than they are during the dry season. Heavy metals are potentially toxic in large quantities or after long-term exposure [41]. They have the ability to move and concentrate in different organs, leading to a variety of health problems [42]. Additionally, certain types of human health problems, including liver failure, gastric and skin cancer, mental health disorders, detrimental effects on the reproductive system, and potentially cancers as well are caused by water containing heavy metal ions [40] [43]. A study conducted by [44] to assess the water quality of the Kufa River in Iraq corroborates the results of this study. This is explained by the variation in rainfall between different seasons. Indeed, during the rainy season, water quantity increases through runoff, which can lead to the intrusion of polluting materials in dam reservoirs. During rainfall, runoff water carries all the pollutants to dams' reservoirs. These results corroborate those of [45], who observe that water quality is poor in rainy season than in dry season on the Hamman Group dam in Algeria, thus making the water undrinkable. These conclusions do not agree with the studies of [46] [47] on surface waters of Oued Moulouya, as well as with several authors such as [48] [49] who noted a higher pollution of the rivers during the dry season compared to the rainy season. This is mostly related to the discharge of wastewater from urban and industrial sources as well as the effects of agricultural practices on water quality throughout the year.

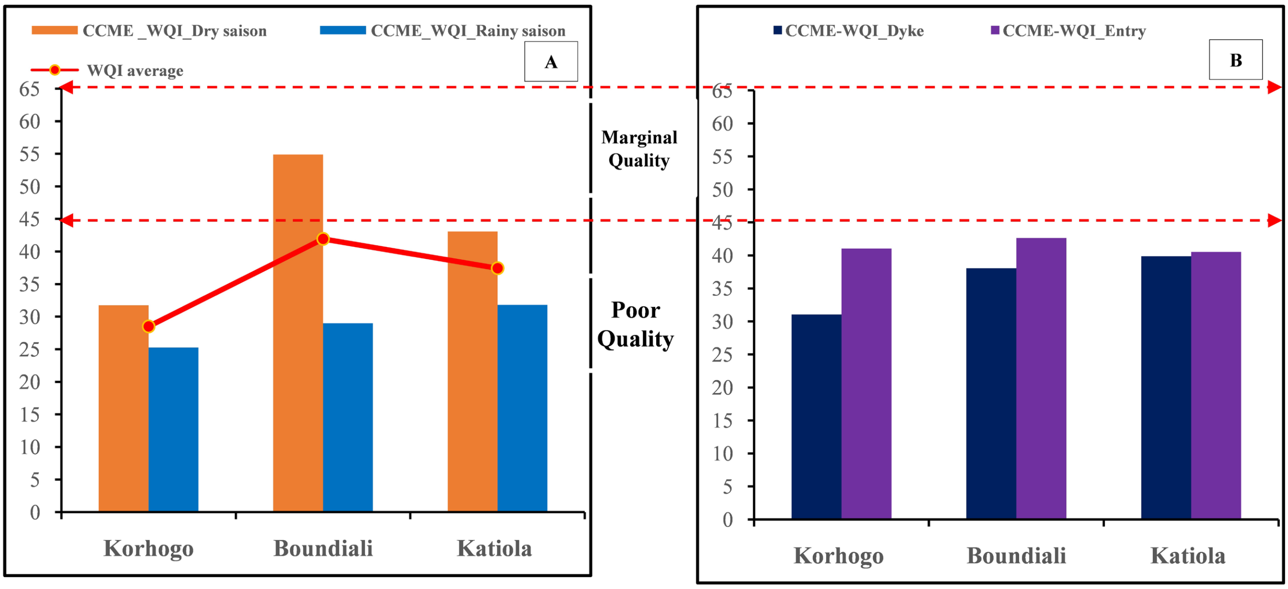

Figure 6. Seasonal (A), Spatial (B) evolution of dams WQI CCME values.

3.3.2. Evaluation of the Organic Pollution Index (OPI)

The calculated OPI values showed that dams waters belong to two pollution classes. These are strong organic pollution and moderate organic pollution. The analysis of **Figure 7(A)** showed that the IPO varied both spatially and temporally. **Figure 7(A)** illustrates the average values of the Organic Pollution Index (OPI) together with the corresponding quality categories. The overall range of these values is 2.38 in Korhogo (strong organic pollution) to 3.1 in Boundiali (moderate organic pollution). The dams in towns or their immediate environs like Korhogo and Katiola are highly contaminated. For the Boundiali the IPO then increases to a value of 3, which indicates moderate organic pollution.

Indeed, the organic pollution is strong during rainy season for all dams except that of Boundiali, which remains moderate. Regarding the dry season, except for Korhogo, which remains in the strong organic pollution class, the others are moderate. However, organic pollution in the Katiola dam is more severe than Boundiali, even though both are in the moderate class (**Figure 7(B)**). This could be explained by the geographical position of the dams. Indeed, these three dams are located in different cities. The Korhogo dam is located inside the city, the Katiola dam on the periphery and the Boundiali dam in the rural area. They receive all the wastewater from cities, which is loaded with organic matter. During rainy season, the amount of water entering in dams increases considerably. Rainfall often results in significant runoff, which can carry organic pollutants such as decaying plant matter, fertilizers, and pesticides, thus increasing the organic pollution index. Indeed, increasing urbanization also contributes to the increase in pollution of dams, particularly from domestic and industrial effluents. Also, the intensification of agricultural activities during rainy season, particularly the use of fertilizers and pesticides, can lead to high nutrient input into dams, promoting eutrophication (excessive nutrient enrichment). This seasonal qualitative variation has been widely reported in the literature by [50]. The qualitative deterioration is mainly of anthropogenic origin in relation to agricultural activities by leaching of soils highly loaded with fertilizers and with the discharge of urban wastewater [51] [52].

Indeed, the discharge of domestic and industrial wastewater from the city's effluents causes an increase in the levels of these parameters which promote the degradation of the quality of the dam water. However, similar work has shown that the increase in the level of pollution in dry season would be linked to the reduction in the flow rates of the dam while those of the effluents loaded with wastewater from the city remain significant [46] [47].

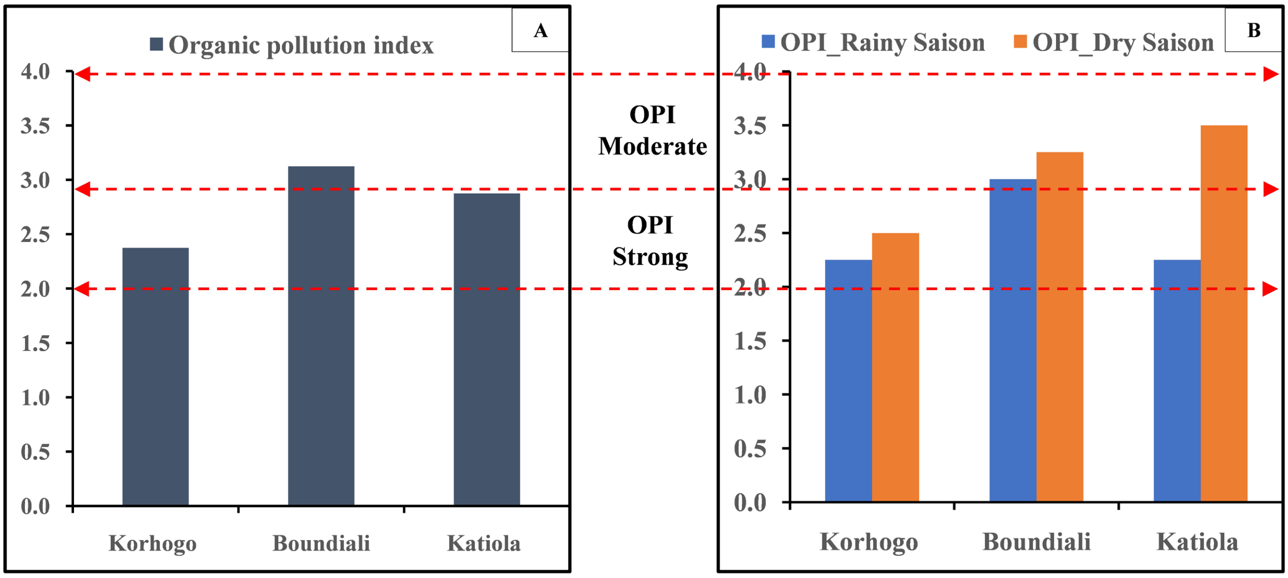

Figure 7. OPI Variation in average (A) and seasonal (B) organic pollution indices (OPI) in dam waters.

4. Conclusion

The characterization of land use over the past twenty-four years reveals significant changes in the watersheds of the three dams. The analyses show a significant decline in natural areas in favor of anthropized areas for the three watersheds of the different level. The most anthropized watershed is Korhogo at 96.23%, followed by Katiola at 83.06% and Boundiali at 53.04%. The dominant anthropic activities in the watersheds are buildings and bare soils for Korhogo, annual crops and fallow land and perennial crops for Katiola and Boundiali. The CCME Water Quality Index assessment indicates that the water quality is poor for all dams, with 28.5 for Korhogo, 37.43 for Katiola, and 41.93 for Boundiali. The most polluted waters in the dams are Korhogo, Katiola, and Boundiali, respectively. The main source of water pollution is organic. Indeed, the organic pollution index is high for the Korhogo and Katiola dams and moderate for the Boundiali dam. Agricultural activities are responsible for this pollution, with total pesticide levels exceeding the JORF standards for drinking water supply. These pesticides are composed of organohalogens, organophosphates, and carbamates. Heavy metals from wastewater, pesticides, and soil leaching are also responsible for this pollution. To reduce this pollution of dam waters, it is important to establish protective perimeters around dams. Integrated water resource management is a long-term solution for better dam management.

Conflicts of Interest

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

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