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Physico-Chemical and Microbial Characterisation of Water from the Abengourou dam in Eastern Côte d'Ivoire

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Abstract: The water from the Abengourou dam is used for the production of drinking water. This study aims to characterise this resource in order to assess the quality of the water for monitoring and sustainability of the operation. Six sampling points were identified, four of which were at the main entrances, one inside the water body and another at the dam. Samples were taken at three different depths and during the two main seasons. In total, some forty physical, chemical and microbiological parameters were monitored for the thirty-six samples taken in one year. The results obtained show an inter-seasonal variation in the parameters monitored. The waters of the dam are very weakly mineralised and not very turbid. The highest turbidity during the wet and dry seasons are respectively 6.5 NTU and 11.1 NTU. The electrical conductivity of the water is between 173 and 190 µS/cm in the dry season and between 149 and 163 µS/cm in the wet season. This is mainly due to rising water levels during the wet season and evaporation during the dry season. Concentrations of iron, pesticide residues, manganese and ortho-phosphate above the WHO guidelines for drinking water were recorded. Average iron levels in the wet and dry seasons are 0.84 and 0.53 mg/L respectively. Manganese levels reached 2.02 in some samples in the dry season. Organohologenes were found at levels up to 0.04 µg/L in the high-water period. A greater presence of germs indicating faecal contamination was found during the high-water period. This contamination is of human or mixed human-animal origin depending on the sampling point. The highest levels are recorded at point P2, which represents the urbanised part of the catchment area for several of the parameters analysed.

Keywords: Abengourou Dam, Microbial Characterisation, Physico-Chemical Characterisation, Surface Water, Water Quality

1. Introduction

Necessary for all forms of life, water is an element that promotes the health of individuals and the socio-economic development of human communities [1–4]. This water is found in several reservoirs such as groundwater and surface water. Despite the existence of these reservoirs, nearly two billion people don't have access to a safe water for daily consumption. The reasons for this include the unavailability of a safe water source, the lack of safe water, the poor quality of the water available, the distance of water points from consumers, and the intermittence of the water supply service.

According to statistics, access to an improved water source was estimated at 20% in 2020 [5–9]. In order to reverse this trend and increase the supply of drinking water, the Ivorian government has undertaken to equip certain cites with additional drinking water supply systems. For the city of Abengourou, in the east of Côte d'Ivoire, the project to extend drinking water coverage provides for the use of raw water from the Abengourou dam. However, due to the anthropic pressure in the catchment area of which this raw water resource to be purified is part, there are threats to the quality of the water which can reduce the storage capacity, lead to health risks and increase the high cost of producing drinking water. Improving the quality of the water consumed by these populations can reduce or even overcome all these problems. The control, monitoring and protection of the Abengourou dam is therefore crucial for the supply of good quality water to the town. However, due to changes in the urban environment (population growth, expansion of the city) and land use (intensification of human activities in the catchment area), it became necessary to understand the current characteristics of the waters of the Abengourou dam. Also, key parameters that could be used to assess water pollution had not been considered in the previous study (pesticide residues, trace metal elements, cyanides).

Hence the interest of this work, which proposes to evaluate the possible threats in order to set up the perimeters and modalities of protection around the water reservoir as well as an appropriate treatment for a sustainable supply of drinking water to the populations of the area.

2. Materials and Methods

2.1. Study Area

The city of Abengourou is located in the east of Côte d'Ivoire, at 210 kilometres from Abidjan, with a latitude of 6°43'47" N and a longitude of 3°29'47" W. Chief town of the Indénié-Djuablin region in the Comoé District, Abengourou is the tenth largest city in Côte d'Ivoire. The Abengourou dam, which is the subject of our study, is commonly called the Adaou reservoir. It is used for drinking water supply and has a surface area of 52.61 km² with a normal water surface of 143 ha. With four (4) water inlets into the dam, the watershed is vegetated with cash crops (cocoa, rubber, banana and teak) and food crops.

The soils are ferralitic and alluvial, hydromorphic, and favourable to crop diversification. However, there is a progressive degradation of these soils with the development of gold panning in the south of the region (Abengourou, Béttié), resulting in the declassification of agricultural soils, the pollution of groundwater and surface water, and the disruption of agricultural activities [10–15].

The climate is determined by the contact between two air masses. A warm and dry air mass (harmattan) blowing from the North-East to the South-West and a cold and humid air mass (monsoon) coming from the Atlantic in the South and circulating towards the North. The contact between these two air masses is called the Intertropical Front (ITF), whose movement between North and South determines the climate [1]. This climate is subject to disturbances due to a delay in rainfall or persistent drought or prolonged rainfall. In Abengourou, annual rainfall amounts recorded from 2000 to 2012 reach 1287 mm to 1656 mm of rain [16].

The geomorphology of the region is marked by a relief characteristic of the middle country, with an altitude that varies from 200 m to 300 m. This relief, on the whole rather monotonous, is interrupted by rare buttes, the highest of which, Ahouribo (extreme East), reaches an altitude of 595 m. In the extreme north-east, there is a system of hills (Zanzan-houd, Dongondi and Messous) with a height of 500 m to 550 m, composed of conglomerates of birimian flysch or metavulcanite.

From a geological point of view, the work of Koudou, A. et al. [17] has allowed to define the litho-stratigraphy of the Abengourou region and to better understand the major lithological units. Thus, the Abengourou region belongs to the Paleoproterozoic (Birimian) domain. It is mainly composed of metamorphosed sedimentary formations, with a high percentage of coarse detrital facies and some intrusive formations and crystalline basement formations which are made up of Birimian formations. In these formations, Eburnian granitoids composed of gneisses, granites, granites-gneisses, with associated aureoles of metamorphism, appear as intrusions. The formations that outcrop in the region are attributed to the Paleoproterozoic and define the Birimian depositional cycle. Their origin is essentially sedimentary, with a high percentage of coarse detrital facies.

Hydrographically, the Comoé River is the main source of surface water in the department. It rises near Orodara (Burkina Faso) and flows into the Atlantic Ocean in Côte d'Ivoire. It is about 1,674 km long, of which 1,160 km are in Côte d'Ivoire. In the region, one of the main tributaries of this river is the Ifou River, which flows northeast of the village of Assikasso. The Adaou (Abengourou) water reservoir is built on a tributary of the Comoé River (Figure 1). The area belongs to the crystalline basement.

The aquifers in the area consist of two superimposed reservoirs. The aquifer of the alterities has a very low effective porosity resulting in low permeabilities except for the strongly leached superficial parts. In the area, the thickness of the alteration varies from 23 to 32 m. The alteration aquifer is only tapped by wells providing low operating and specific flows. The water quality is poor due to the numerous clay minerals and the risk of water pollution from the surface. These aquifers receive water directly from rainfall and their piezometric levels drop considerably in the dry season and rise in the rainy season [18].

Groundwater is more easily accessible through modern wells, traditional wells or temporary sumps dug in the lowlands during the dry season. Granito-Migmatite reservoirs are the most widespread in the area. These are fractured aquifers in which there are several water inflows provided that the fractures are not sealed. In the area, the depth of the boreholes encountered varies from 22 to 96 m. The thickness of the drilled bedrock varies from 16 to 48 m. The geological formations in the area are very good aquifers in terms of both quantity and quality of reserves. The flow rates encountered vary from 1.5 to 7 m^3/h. In the project study area, these aquifers are tapped by numerous boreholes equipped with human-powered and electric pumps.

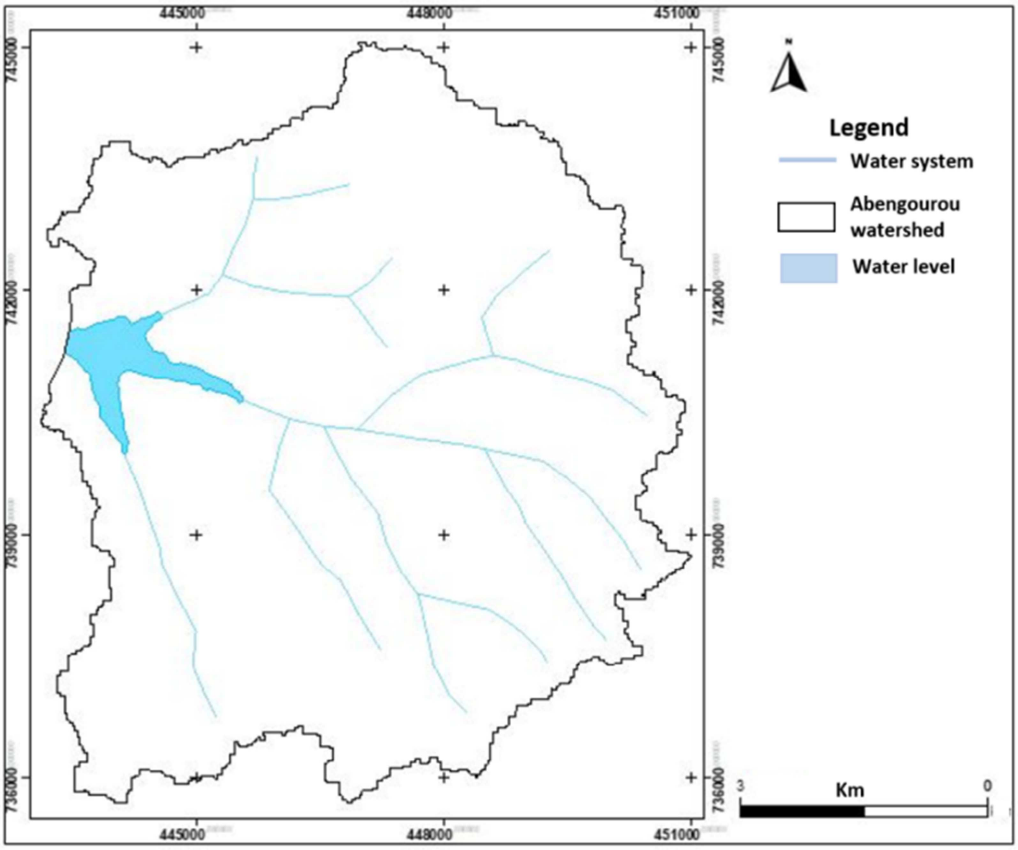

Figure 1. *Location of the Watershed of the Abengourou Dam.*

2.2. Water Quality Monitoring

Water quality assessment and monitoring is necessary and covers a number of parameters such as physicochemical parameters, hydro morphological status, biological parameters and chemical parameters [13, 19, 20]. The actions implemented for the monitoring are firstly to select the sampling stations according to the objectives of the study, then to define the in-situ measurements to be carried out (pH, conductivity, temperature) and the parameters to be analysed (physicochemical, micropollutants, biological), and finally to determine the sampling frequency. In a second phase, the sampling campaigns are carried out at the selected stations according to the in-situ measurements and the sampling technique (s) selected. This phase, as well as the packaging, transport of the samples to the laboratory and storage (darkness and adequate temperature), must be carried out with the utmost care, as it conditions the validity and representativeness of all the analyses that will be carried out subsequently on the sample. Note that it is also important to record all observations on the environment (climatic conditions, hydrology, plants, etc.) of the station at the time of sampling, as they are likely to help in the interpretation of the data. Then, the samples are received in the laboratory, followed by the analyses selected during the planning phase, each laboratory having its own quality assurance system. Finally, the data must be processed, used and communicated. This must be done in accordance with the final information required. It is also important to record all observations on the environment (climatic conditions, hydrology, vegetation, etc.) of the station during sampling, as they are likely to help in the interpretation of the data.

2.3. Sampling and Analytical Methods

Many countries have developed their own methods, adapted to local conditions and possibly inspired by one or other of the existing methods. The methodology adopted in the conduct of this study is based on a systemic approach, focusing on continuous consultation. This enabled us to identify the various sources of pollution potentially present in the environment of the reservoir. Two sampling campaigns were carried out during the rainy season or high-water period and during the dry season or low water period. Samples were taken in July 2021 for the rainy season and in February 2022 for the dry season. The samples were taken in accordance with the recommendations for the analysis of physico-chemical and microbiological parameters according to standard methods [6, 21]. To characterise the raw water of the dam, we defined six (6) sampling points for 36 samples per point on the Abengourou dam (Figure 2). These samples were defined according to the different water arrivals in the number of four (P1, P2, P3 and P4), one in the centre (P5) and another near the dam (P6). We proceeded in this way throughout the dam to ensure the homogeneity and representativeness of the different parameters analysed at each inlet. For each point, samples were taken at three depths (surface, middle and bottom of the dam). For each sample, 22 parameters were measured, including 16 physico-chemical and 4 microbiological parameters. Within the framework of this work, we used borosilicate glass, polypropylene and polyethylene bottles of 1.5 litres. The bottles intended for sampling for the analysis of mineral elements were treated with nitric acid, then rinsed abundantly, drained and not dried. The maintenance of a humid atmosphere makes it possible to eliminate possible contamination of the bottle by rinsing it at the time of sampling. For packaging, the samples were packaged in bottles cleaned without detergent to avoid contamination by ortho-phosphates and organic matter [6].

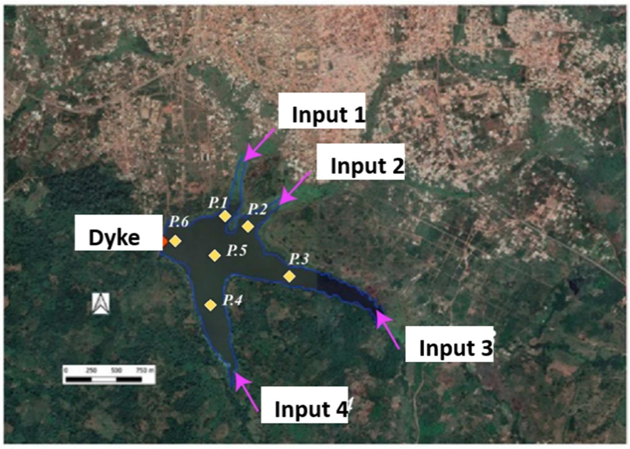

Figure 2. *Overview of the Abengourou Dam and Sampling Points Location.*

Physical parameters such as temperature, pH and electrical conductivity were obtained by using a multi-parameter field probe (AQUAREAD AP-2000). A microwave-generated plasma atomic emission spectrometry (MP-AES 4210 Agilent) has been used for trace metal elements and metals analyses: arsenic (As), lead (Pb), iron (Fe), manganese (Mn) and mercury (Hg). Nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), orthophosphate (PO_4^{3-}), and COD were characterised by molecular absorption spectrophotometry (DR 3900 Hach). BOD5 was determined by incubation in a thermostatic chamber with Oxytop. Pesticides residue (organochlorines, organophosphates, carbamates) were characterised by gas chromatography-mass spectrometry (GC-MS). The microbiological analyses allowed the detection of total coliforms, faecal coliforms, and faecal streptococci. These germs were detected by the membrane filtration method. The following media were used: KF agar (Selective medium used for the isolation and enumeration of enterococci in food products by the classical Petri dish method) for faecal streptococci, ID Coli (culture medium for the identification of Escherichia coli) for total coliforms [22–25]. Petri dishes were then incubated for 24 hours and 48 hours.

2.4. Determination of the Pollution Index

In order to have a clearer and more precise idea of the organic pollution of the water of the Abengourou dam, we used the organic pollution index (IPO) [26]. The principle of the OPI is to divide the values of the polluting elements into five classes. This index is obtained by means of ammonium, BOD5, nitrite and orthophosphates. The principle of the calculation is to divide the values of the four pollutants into five classes and to determine, from the values obtained in the study, the corresponding class number for each parameter using the average data in Table 1. The final index is given by the average of the class numbers.

Table 1. *Limits of the Organic Pollution Index Classes [27].*

Classes	NH_4^+ (mg/L)	DBO_5 (mgO_2/L)	NO_2- (µg/l)	PO_4^{-3} (µg/L)	OPI	Organic pollution
5	<0.1	<2.0	<5	<15	4.6-5.0	Null
4	0.1-0.9	2.1-5.0	6-10	16-75	4.0-4.5	Low
3	1.0-2.4	5.1-10.0	11-50	76-250	3.0-3.9	Moderate
2	2.5-6.0	10.1-15.0	51-150	251-900	2.0-2.9	High
1	>6.0	>15.0	>150	>900	1.0-1.9	Very high

3. Results and Discussions

3.1. Water Inflow into the Abengourou Dam

The Abengourou dam, also called the Adaou reservoir, is a tributary of the Comoé River. The river on which the dam was built is fed by 4 entry points (Figure 3). The first inlet drains about 5% of the total basin area in the northwest. This is a fully urbanised area. The flow axis passes through a large floodplain before entering the dam. The flow is only present during rainfall, otherwise the water is low and stagnant. All upstream of this axis there are systems of pipes and gutters that drain the water from the city to the floodplain.

The second entry point (P2) drains about 18% of the total basin area to the north and north-east. It is a mainly urbanised area. The flow is particularly active in the event of rain. A little further upstream, 500 m from the first observation point, there is a double nozzle system where the water velocity was measured. Approximately 500 m upstream of the entry point P2 there is a relatively large flow in a large plain and near a landfill.

Entry point P3 drains the largest part of the catchment area, i. e. 60% of the total area. The land use of the drained area is mainly natural, except for an extension of the town of Abengourou and some dwellings. It appears to be significant, however, as evidenced by the overflows on the runway. The fourth entry point, P4, drains more than 15% of the surface area of the catchment area in the south-western part of the catchment. The land use is exclusively forestry and agricultural. The water supply is permanent during the rainy season.

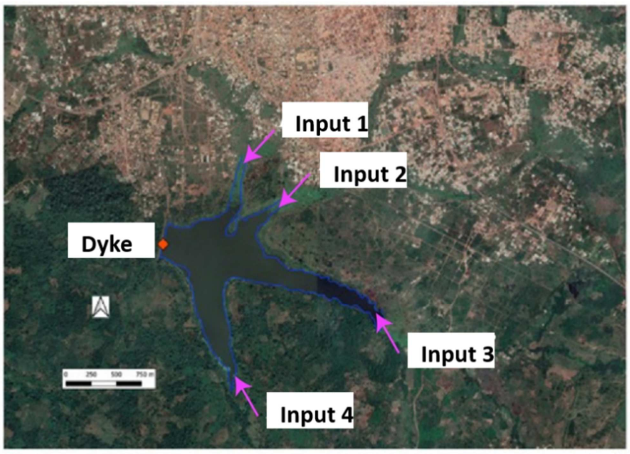

Figure 3. *Main Water Entry Points into the Abengourou Dam.*

3.2. Sources of Pollution Around Abengourou Dam

The Abengourou dam was built in an urbanised catchment area with significant anthropogenic activities in the area. After the investigations, three potential sources of pollution were identified.

Firstly, the city's sanitation and the population's waste and excreta management practices can influence the pollution of the water body. A part of the catchment area is characterised by anarchic dwellings upstream of the dam which exert a strong pressure on the quality of the water. In the study area, there are precarious housing areas, without any individual or collective system for collecting and treating domestic waste or an almost non-existent urbanisation plan. The water reservoir has therefore become the main receiving environment for rainwater, which also carries mineral and organic substances in suspension. The outlet for this collected water is the tributaries which constitute the P1, P2 and P3 entry points of the reservoir. The observation also revealed eutrophication of these tributaries, which indicates the presence of nutrients responsible for this environmental disturbance.

Secondly, there is chemical pollution linked to the crops grown in the beds of the reservoir's tributaries. Agricultural activities constitute the major part of the activities in the catchment area. The crops grown are cash crops such as cocoa, coffee and rubber and food crops. In the low-lying area created by the runoff from the P1 and P2 entry points, rice and market gardening are practiced. The use of fertilisers, herbicides and insecticides to control insects and weeds could be a major source of pollution of the reservoir. When the forest is cleared, forest products are burnt, the nutrient supply of the soil and plant material is progressively depleted by selective erosion and leaching due to changes in land use and surface conditions.

Part of the lake on the right bank at the approach to the dike is silted up. A strong eutrophication is observed in the two tributaries in the northern part. This leads to an enrichment of the water with nutrients, which causes a series of symptomatic changes, such as an increase in the production of algae and macrophytes, degradation of water quality and other symptomatic changes considered undesirable and detrimental to the various uses of the water [27].

Another source of pollution that has been highlighted is livestock farming. This activity mainly concerns cattle fattening. Breeders use the water from the dam to water their cattle. The animals have direct access to the dam's reservoir, so their droppings and daubs in the dam's water constitute an important potential source of water pollution. All this information collected in the field was coupled with satellite data to generate the land use map shown in Figure 4.

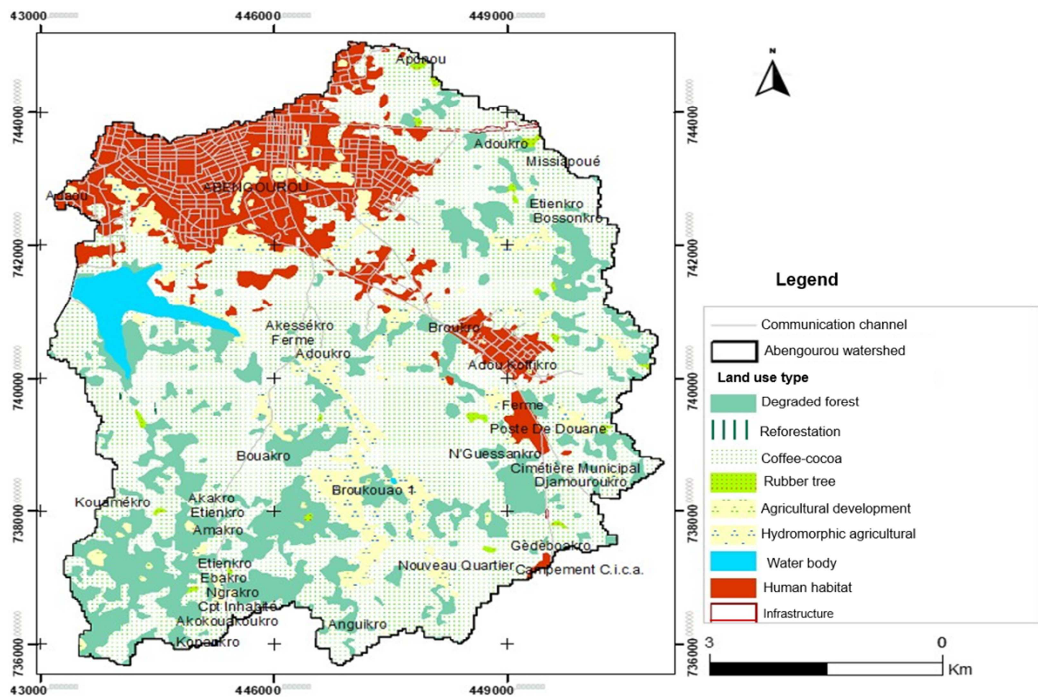

Figure 4. *Land Use Map of the Abengourou Reservoir Watershed (source: Land Cover Extracted from Sentinel-2a Satellite Images 2015-2016 10m Resolution).*

3.3. Characteristics of the Water of Abengourou Dam

To highlight the characteristics of the water of the dam, physicochemical and microbiological parameters were highlighted from samples taken in the dry and wet seasons.

3.3.1. Physical Characteristics of the Waters of Abengourou Dam

The electric conductivity of Abengourou dam samples are between 149 and 163 µS/cm in the high-water period and between 173 and 190µS/cm for the low water period. The conductivities obtained are low compare to the usual value from surface water in the area. These results show very little mineralisation of the water. It is noted a variation of this parameter from one period to another. The seasonal variations in conductivity can be explained by the dilution phenomenon experienced by the dam water during the rainy season. On the other hand, in the dry season, evaporation will lead to a concentration of dissolved pollution, particularly the ion load. The concentration of these ions will lead to an increase in electrical conductivity with an average value of 198 µS/cm. The low periodic variations obtained also show the non-existence of occasional anthropogenic inputs of particular waters (discharges of ion-loaded industrial wastewater). This seems to agree with the field observations where, apart from charcoal production companies, no industrial units have been recorded in the catchment area.

Abengourou dam water turbidity varies between 4.6 and 6.5 NTU in the dry season and between 6.3 and 11.1 NTU in the rainy season. The low levels in the dry season could be explained by the settling of the water which leads to a clarification of the water on the surface due to the concentration of colloidal particles and coarse elements in the depths. During the rainy season, the runoff of water towards the dam leads to the drainage of all kinds of waste and soil debris and the resuspension of dissolved particles, thus disturbing the water. The turbidity of inlet P3 is the highest. As this point drains water from an agricultural area, this result can be explained by soil flows from cultivated areas [28].

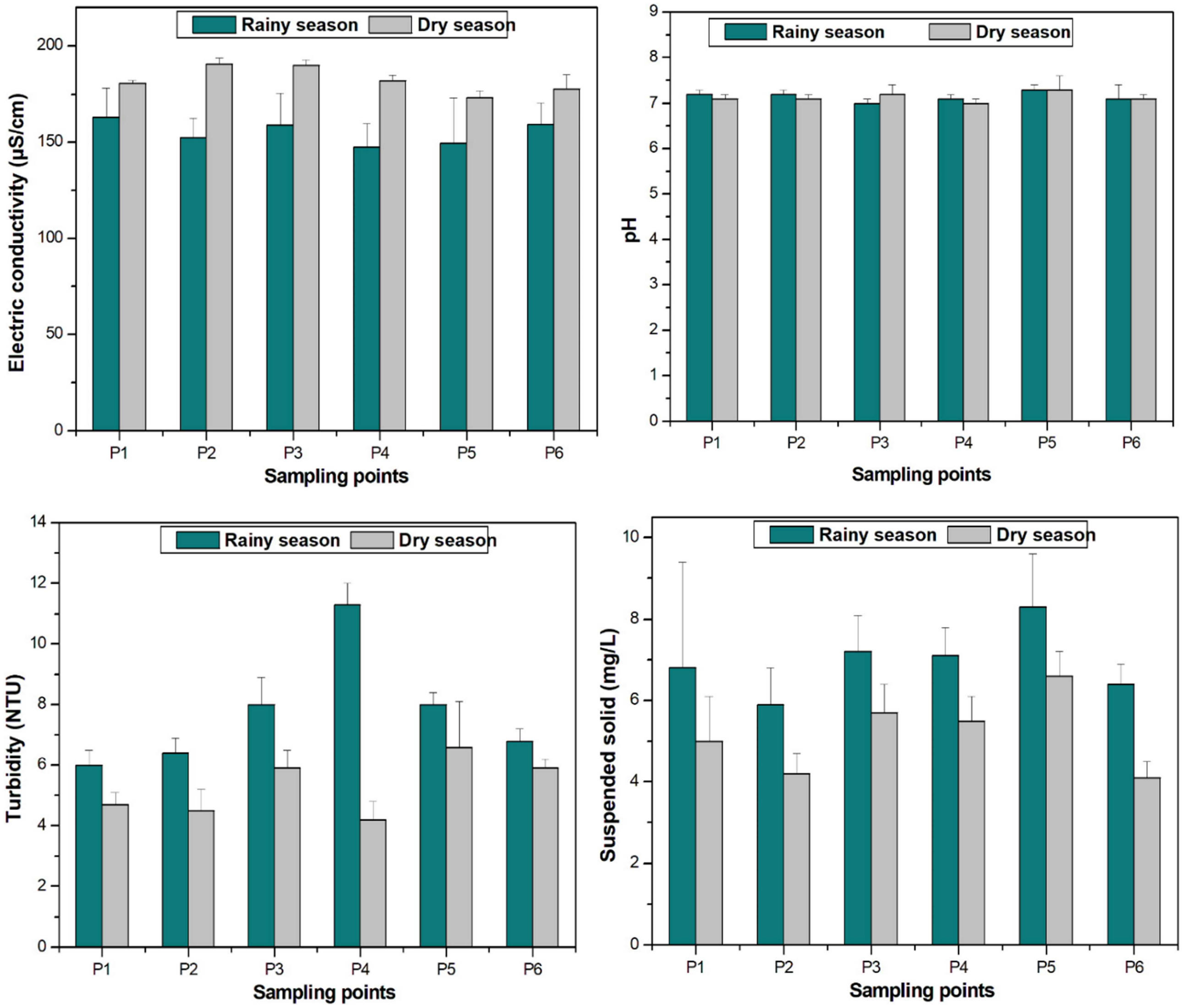

Figure 5. *Variation of some Physical parameters of the Abengourou Dam Water (Electric Conductivity, pH, Turbidity, Suspended Solid).*

An identical trend was obtained with suspended solids (SS). The average TSS content was higher in the rainy season than in the dry season with 6.93 and 5.18 mg/L respectively. This increase in TSS during the rainy season is undoubtedly linked to the inflow of runoff water, which is fairly high in particles. On the other hand, there is a decrease in the dry season due to decantation. The highest TSS content was recorded at point P5. As this sampling point is located within the catchment area, it is noted that the TSS from the four entry points migrated to concentrate within the dam leading to this high value.

The Abengourou dam water has a practically neutral pH that varies between 7.0 and 7.3 in the rainy season, compared to 7.0 and 7.1 in the dry season. The pH of the water remains almost constant during all seasons.

Water always contains dissolved gases, the concentrations of which depend on the temperature and the composition and pressure of the gaseous atmosphere with which it is in contact. The solubility of gases in water gives an idea of the chemical and biological phenomena that can take place in the sample. Examination of the seasonal evolution of dissolved oxygen shows high levels in the rainy season of 6.5 to 9.3 mg/L, compared to the dry season of 5.4 to 7.2 mg/L. During the rainy season, the movement of water due to precipitation leads to oxygenation and therefore an increase in the dissolved gas content. In the dry season, however, the high heat leads to evaporation of water and gases, which in turn leads to a decrease in dissolved oxygen content [15]. Figure 5 shows the evolution of some physical parameters of Abengourou dam water.

3.3.2. Chemical Characteristics of Abengourou Dam Water

Ammonium, nitrite and nitrate ion levels were used to assess mineral nitrogen pollution. The evolution of ammonium ion concentrations in the reservoir water showed average levels of 0.69 mg/L and 0.60 mg/L respectively in the rainy and dry seasons. Ammonium concentrations measured in the wet season are higher than those obtained in the dry season. The values are higher in the wet season due to the direct input of nitrogenous elements from runoff. However, in the dry season, ammonium is transformed into nitrite and then into nitrate, which explains the decrease in ammonium in the dry season. Its presence in the water of the dam could be explained by the fertilisers used for the crops. These observations show that both agriculture and livestock farming in the catchment area are potential sources of ammonia nitrogen.

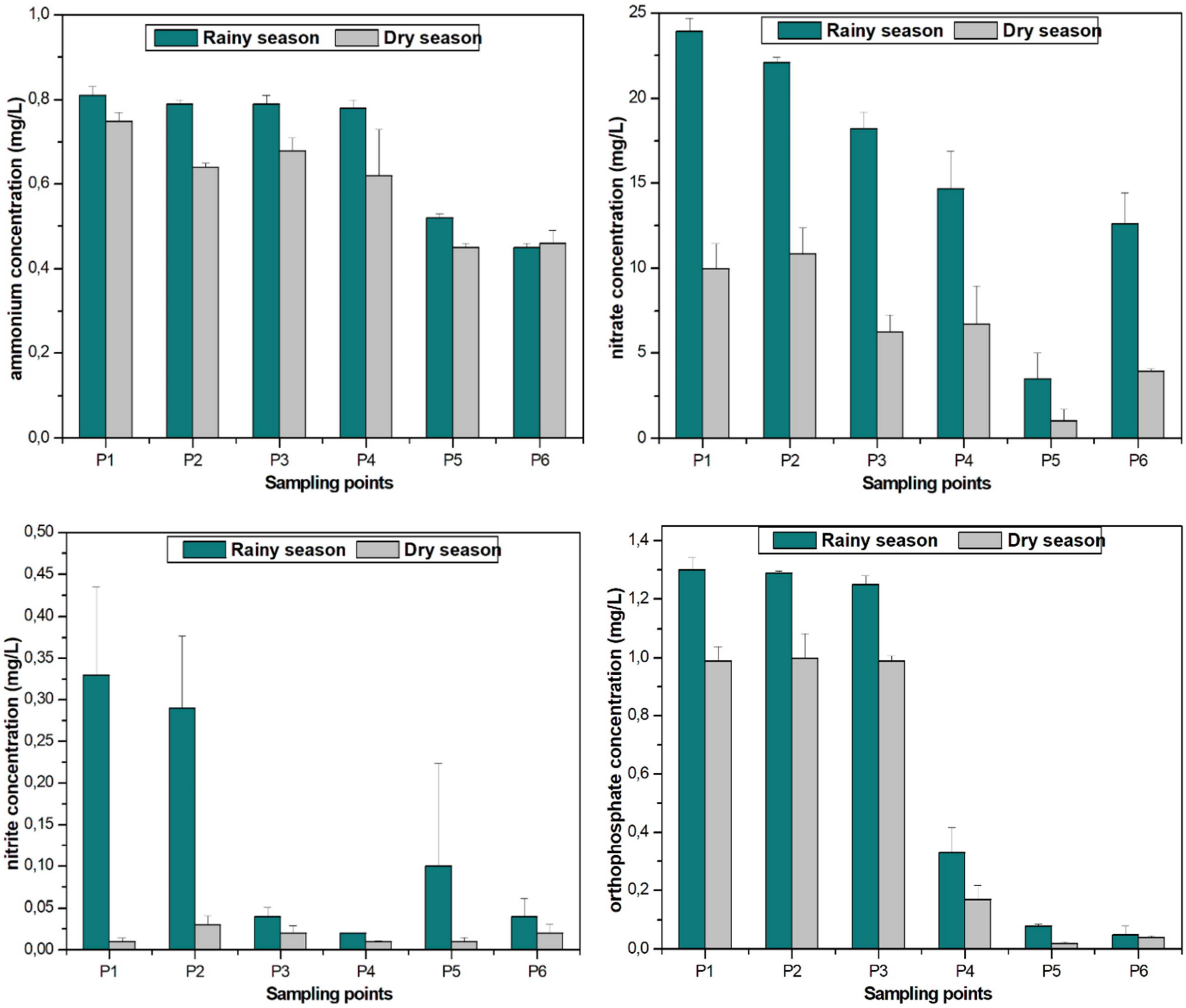

Figure 6. *Evolution of Mineral Parameters in the Dam (Ammpnium, Nitrate, Nitite, Orthophosphate).*

The average nitrate ion concentrations (NO_3^-) in the Abengourou dam are 15.83 mg/L and 6.45 mg/L in the rainy and dry seasons respectively. The nitrate values during the high-water period are higher than during the low water period. Like ammonium, this is due to the leaching of fertilisers used in agricultural soils and animal manure as well as the discharge of raw sewage from the city of Abengourou. The nitrites originate either from incomplete oxidation of ammonia, as nitrification is not completed, or from a reduction of nitrates under the influence of a denitrifying action. The results of the nitrite (NO_2^-) content show average values of 0.135 mg/L and 0.0173 mg/L in the rainy and dry seasons respectively. Concentrations in the dry season are very low or almost zero at some sampling points. As nitrite is an intermediate form that appears during the oxidation of ammonium, the near absence in dry season waters seems logical.

The concentrations of orthophosphate ions vary from 0.01 to 0.99 mg/L for the low water period and between 0.05 and 1.30 mg/L for the high-water period. The presence of ortho-phosphate ions in the water is related to the characteristics of the land and the decomposition of organic matter. According to the WHO, the limit value for ortho-phosphate is 0.5 mg/L. Only sampling points P4, P5 and P6 with values ranging from 0.05 to 0.33 mg/L in the rainy season and from 0.01 to 0.17 mg/L in the dry season are acceptable. However, points P1, P2 and P3 ranging from 1.25 to 1.30 mg/L in the wet season and 0.99 to 1.00 mg/L in the dry season are above the recommended value. The increase in phosphorus load contributes to eutrophication [12].

The physico-chemical parameters varied according to the season and the sampling point. Apart from the electrical conductivity, which increased in the dry season due to evaporation, which led to a concentration of ions, the other parameters are higher in the rainy season than in the dry season. The points corresponding to the water inlets in the reservoir generally have higher levels than points P5 and P6 inside the dam. There is also a tendency for concentrations to decrease as one moves away from the banks due to a dilution effect and sedimentation of certain soluble compounds [29]. On the other hand, the differences in characteristics at the level of the inlets show that it is the nature of the land in contact with the runoff and also the types of activities practised in the catchment area that condition the characteristics of the water.

3.3.3. Organic Pollutant

Chemical oxygen demand (COD) and pesticide residues were selected for the assessment of organic pollution in the reservoir [6]. The COD concentrations at each sampling point are presented in Figure 7. COD ranges from less than 3.0 to 56.0 mg O_2/L in the rainy season and from 83.0 to 231.0 mg O_2/L in the dry season. As this parameter is dependent on both suspended and soluble particles, the accumulation of particles due to water withdrawal leads to an increase in concentration. Indeed, due to dilution in the rainy season, the elements are mainly dissolved, hence the low values. During the dry season, due to evaporation, there will be a concentration of dissolved pollution, including organic pollution, which will lead to an increase in COD. Point P5 in the centre of the reservoir has the highest value. This concentration is more pronounced at points P5 and P6 because the water received by the different inlets will accumulate at the centre (P5). This accumulation leads to a peak at this point which then migrates towards the dyke (P6). The trends observed are different depending on the season. This could be explained by the differences observed in the water flows through each of the inlets.

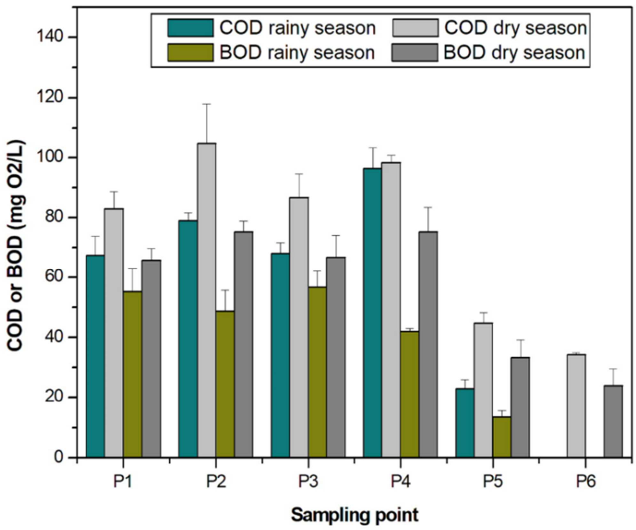

Figure 7. *Evolution de la DCO de l'eau du Barrage d'Abengourou.*

Table 2. *Pesticide Residues Concentration in Abengourou Dam Water.*

Pesticide family	Organohalogen pesticides (µg/L)		Organophosphorus pesticides (µg/L)		Carbamate (µg/L)	
Period	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
P1	0.04	0.01	<0.01	<0.01	<0.01	<0.01
P2	0.04	0.02	<0.01	<0.01	<0.01	<0.01
P3	0.03	0.02	<0.01	<0.01	<0.01	<0.01
P4	0.03	0.01	<0.01	<0.01	<0.01	<0.01
P5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 2 shows the pesticide residue levels for the three families (organophosphates, organochlorines and carbamates) in the dam water. The pesticide residue results presented in Table 3 show an absence of organochlorine and carbamate pesticide residues. Only organohalogen pesticide residues are present in the dam water with concentrations between 0.03

and 0.04 µg/L in the rainy season and between 0.01 and 0.02 µg/L in the dry season. Organohalogen pesticides are widely used for soil, forest and crop treatment. Their presence in the water of the dam would result from the agricultural activities practiced around the catchment area. They are found in the water by transport through runoff with soil leaching and contact with plants, but also by air transport. Concentrations below the detection limit (0.01 µg/L) were obtained at point P5 in the centre of the reservoir and P6 at the dam. The increase in the quantities of water at points P5 and P6 could lead to a dilution of these pollutants and would be the cause of the low concentrations found at these points.

3.3.4. Metals and Trace Metals

Dissolved iron values (Figure 8) are not negligible in both seasons. Concentrations vary between 0.53 and 1.01 mg/L in the wet season and between 0.42 and 0.64 mg/L in the dry season. During the dry season, iron levels drop. This decrease is due to oxidation by oxygen on the one hand, and to the mixing of the water in the dam on the other. During the rainy season, iron levels become high due to runoff from the catchment. However, although these ions are not harmful to humans, they do cause discomfort to consumers. They give a reddish or blackish colour and a bad taste to the drinking water. All these values are well above 0.3 mg/L, the threshold value of the WHO guidelines for drinking water [30].

The evolution of manganese shows that the manganese content is almost zero with a value of less than 0.10 mg/L in the dry season. However, in the rainy season, we can observe high values ranging from 1.93 to 2.02 mg/L. The recorded concentrations are above 0.40 mg/L, the WHO threshold value [31]. These high concentrations can be explained by gold panning activities in the town of Bongouanou, not far from Abengourou. Manganese, which occurs naturally in several types of rock, is one of the most abundant metals in the environment. It is found in drinking water, mainly in groundwater supplies, but also possibly in surface water. Anthropogenic sources, such as industrial discharges, mining or landfills, can increase its concentrations in drinking water sources. This high presence of manganese can give an undesirable taste to water (rather bitter, metallic, astringent). In high doses, in mammals, manganese affects fertility and is toxic to the embryo and fetus [16, 17].

Arsenic, lead and mercury are almost non-existent in the sample collected in Abengourou dam. The concentrations recorded are all below the detection limits of the atomic emission spectrometer (Table 3).

Table 3. *Metals and Trace Metals Concentration in Abengourou Dam Water.*

Parameters	Sampling point	P1		P2		P3		P4		P5		P6	
	Sampling period	RS	DS	RS	DS	RS	DS	RS	DS	RS	DS	RS	DS
As (µg/L)		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Pb (µg/L)		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Hg (µg/L)		<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Mn (µg/L)		2.00	<DL	1.65	<DL	1.68	<DL	1.77	<DL	2.02	<DL	1.74	<DL
Fe (mg/L)		1.01	0.64	0.85	0.59	0.53	0.42	0.90	0.54	0.93	0.50	0.84	0.46

DL: Detection limit
RS: Rainy season
DS: Dry season

3.3.5. Microbiological Characteristics of the Dam Water

The results of the microbiological analyses of the samples collected in Abengourou dam reveal a significant bacterial load during the two seasons. Point P2, representing the point of entry into the urbanised part of the catchment, has the highest loads. This bacterial load could be explained by the non-existent sanitation system in the districts. In particular, the observations showed that the city of Abengourou has an inadequate sanitation system and an environment characterised by the presence of rubbish dumps and the stagnation of wastewater in several places. This load is more pronounced during the rainy season due to run-off water, which drains all the waste from dumps, livestock pens (cattle, sheep), and open defecation sites throughout the town and its neighbourhoods. In the dry season, this load decreases due to the disappearance of certain germs from the environmental conditions. he lowest loads are recorded in the centre of the reservoir and at the level of the dyke. The evolution of the microbiological parameters is shown in Figure 8. The ratio of thermotolerant coliforms to faecal streptococci was used to determine the origin of the contamination of the water [32]. The values of this ratio in the case of the present study are between 1.66 and 17.00. This makes it possible to deduce that the faecal contamination of the waters of the Abengourou dam is exclusively human for most of the sampling points. Mixed human and animal contamination were found at point P5 during the wet season and at points P1 and P3 during the dry season. This result confirms that livestock farming also contributes to the degradation of the water quality of the dam.

3.4. Determination of the Pollution Index

Based on the organic pollution parameters (BOD5, NH_4^+, NO_2^-, PO_4^{-3}), the organic pollution was evaluated over the two seasons (rainy season, dry season). The determination of the IPO shows that the Abengourou dam faces a very high organic pollution at the level of points P1 and P2, a high organic pollution at the level of P3, P4 and P5 while a moderate pollution is observed at the level of P6 (Table 4). Contrary to the rainy season, which presents a very high pollution in some places, in the dry season the dam presents two levels of pollution, namely a high pollution observed at points P1, P2 and P3 against a moderate pollution at points P4, P5 and P6 (Table 4). In the rainy season, organic pollution is more pronounced than in the dry season due to the intrusion of organic pollutants with runoff water.

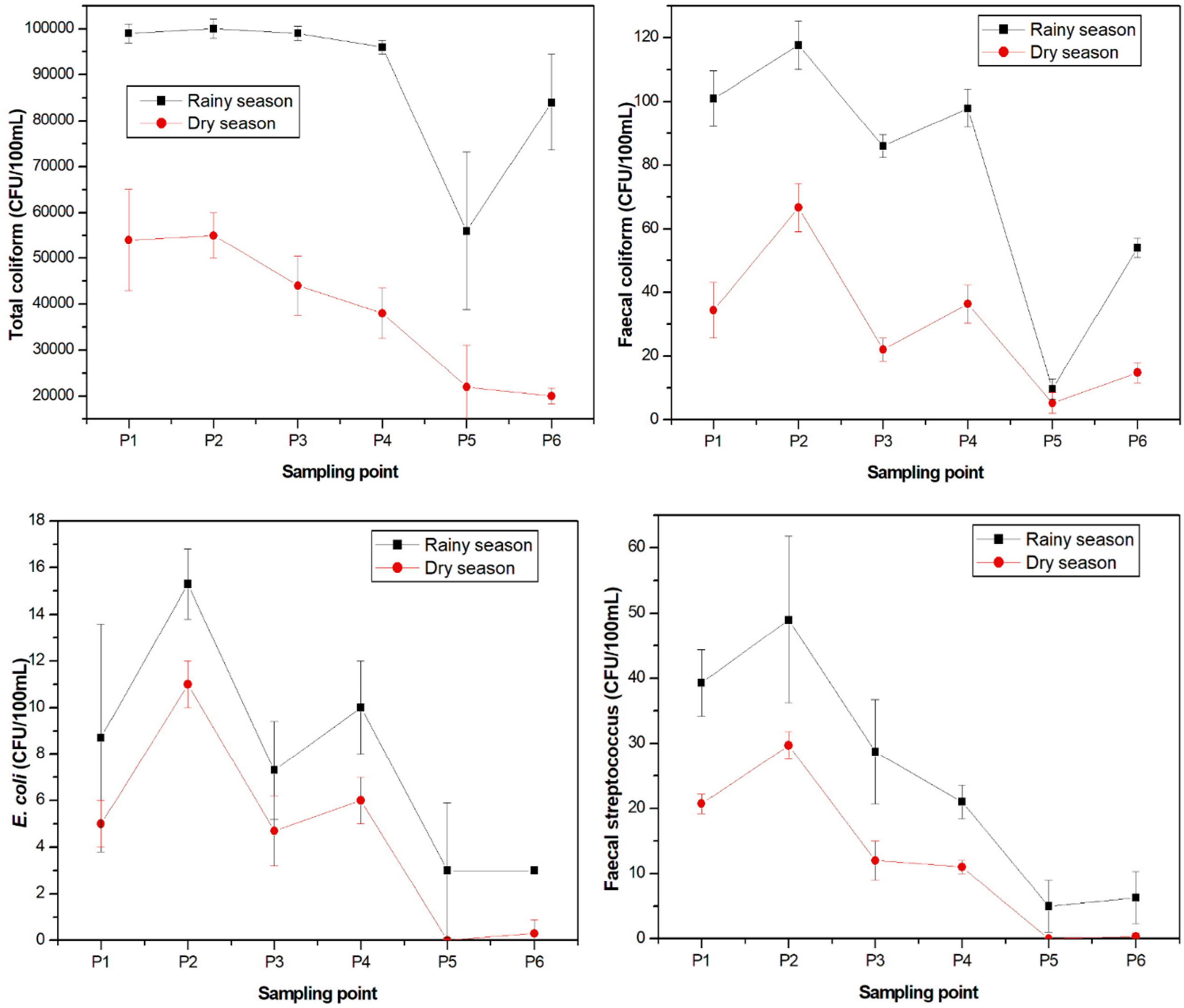

Figure 8. *Variation de la Concentration des Germes Pathogènes.*

Table 4. *Determination of the Pollution Index.*

	Classe					
	NH_4^+ (mg/L)	BOD5 (mg O_2/L)	NO_2^- (µg/l)	PO_4^{-3} (µg/l)	OPI	Organic pollution
Rainy season						
P1	4	1	1	1	1.8	Very high
P2	4	1	1	1	1.8	Very high
P3	4	1	3	1	2.3	High
P4	4	1	3	2	2.5	High
P5	4	1	2	3	2.5	High
P6	4	4	3	4	3.8	Moderate
Dry season						
P1	4	1	3	1	2.3	High
P2	4	1	3	1	2.3	High
P3	4	1	3	1	2.3	High
P4	4	1	3	4	3.0	Moderate
P5	4	1	3	4	3.0	Moderate
P6	4	1	3	4	3.0	Moderate

4. Conclusion

The waters of the Abengourou dam were characterized during the dry and rainy seasons. Samples were taken at the four main water entry points to the dam, in the centre of the reservoir and at the dam. The analyses concerned selected parameters that could give an account of the physical, chemical and microbiological characteristics, but also to assess the level of water pollution. The observations highlighted a catchment area around which agricultural activities are practised and where discharges of excreta and domestic wastewater are observed. A variation of values according to the seasons was revealed as well as different values according to the sampling points. Residues of organohalogen pesticides were obtained in relatively large quantities as well as high concentrations of manganese and iron. As these pollutants refer to agricultural and artisanal gold mining activities, it appears that anthropogenic activities in the catchment area have an influence on the quality of the water in the dam. The assessment of the pollution index shows that the water quality changes from highly polluted to moderately polluted. This influence leads to changes in the water level and can affect the quality of the treatment that will be implemented. The water from the Abengourou dam, in order to be used for drinking water supply, must undergo a treatment that includes a refining stage to eliminate pesticide residues and manganese.

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