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Assessment of Lagoon Water Quality for Drinking use based on Multivariate Analysis: the case study of Adjin, Ivory Coast

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Abstract: The use of the Adjin lagoon as an alternative source of drinking water supply for Abidjan city requires the assessment of its pollution status. To this end, seasonal physico-chemical analyses were carried out on seven waters stations sampling. The water quality data obtained were subjected to statistical tests of One-way ANOVA, Factor analysis, Cluster analysis and as well as Water Quality Index (WQI) using evaluation of Canadian Council of Ministers of the Environment model. Temporally, One-way ANOVA test showed that the values of water quality parameters studied are significantly ($p < 0.05$) higher during the rainy season than the dry season. This suggests that water quality is influenced by rainfall. Spatially, the results of Factor and Cluster analysis confirmed that the upstream part of Adjin lagoon is subject to organic pollution (total phosphorus, permanganate index, COD and BOD5) of anthropic origin linked to domestic waste and sediments transported from the villages and communes around the lagoon. In the intermediate part, there is nitrogenous pollution linked to the fish farming practices carried out on the water body. Downstream, water is more turbid. WQI values of different stations (WQI < 44) revealed that waters sampling were a poor quality compared to the target water quality range recommended by Ministry of Health and Public Hygiene and Ministry of Water and Forestry of Ivory Coast. Also, poor water quality was recorded in all seasons with the exception of the long dry season (WQI = 47.7) which recorded marginal water quality.

1. Introduction

Inaccessibility to safe drinking water is an obstacle to good hygiene practices and a risk factor for infectious diseases. This is the main reason why the United Nations has defined access to water and sanitation for all and ensuring sustainable management of water resources as a Sustainable Development Goal (SDG) by 2030. Countries bring significant political weight behind the notion that access to clean and safe drinking water free of pollutants as nitrates, heavy metals, pesticides… (Bouknana *et al*. 2014; Errami *et al*, 2013; Alaqarbah *et al*., 2022). According to the UNDP, achieving this goal requires sufficient and hygienic water supply facilities (PNUD, 2018). This is why in Côte d'Ivoire, an emergency presidential programme to improve the provision of water and sanitation services has been put in place according to the latest Afrobarometer survey conducted in 2020 (Koné and Silwé, 2020). This programme consists on the one hand of the construction of new water supply systems for localities that do not have them. On the other hand, for localities in deficit that already have water supply, the construction and connection of new boreholes and the strengthening of surface water treatment capacities (Koné and Silwé, 2020). Despite these efforts, the populations of many Ivorian cities still do not have continuous access to these services, and disapprove of the government's performance in this area (Koné and Silwé, 2020). This is the case in Abidjan, the country's economic capital, where the need for water is crucial in several parts of the city. Indeed, the production of drinking water in the district of Abidjan, estimated at 640,000 m3/d from groundwater, remains insufficient for a population estimated at ten million inhabitants (INS, 2014). This deficit is mainly due to the unpredictable population growth and the decline in borehole productivity (Koné and Silwé, 2020). The use of groundwater is no longer sufficient to meet Abidajan's drinking water needs on a sustainable basis. The only sustainable solution is to use surface water. It is in this context that the Adjin lagoon, which belongs to the Ebrié lagoon system, one of the three lagoon systems of Côte d'Ivoire, was chosen to reinforce the drinking water supply of Abidjan. Little data on the water quality of this lagoon is available, however, as the numerous studies carried out on the Ivorian lagoon system have mainly focused on larger environments such as the Ebrié, Aby and Grand-Lahou lagoons (Yao *et al*., 2009; Komoé, 2010). However, small coastal ecosystems such as Adjin were very rich, especially for the riparian populations as they ensured the subsistence of domestic and recreational uses (Niamien *et al.,* 2008). Due to the rapid urbanisation of the city of Abidjan and the agricultural activities developed in the catchment area of the Adjin lagoon, favouring inputs of contaminants of natural and anthropogenic origin, the quality of the water of this lagoon may be deteriorated. Given the vulnerability of this surface water to pollution, the prevention and control of pollution in the Adjin must be based on reliable water quality analysis and identification of pollutant sources (Shrestha and Kazama, 2007). Monitoring data are usually analysed using statistical methods (Yidana, 2010). Techniques such as Principal Component Analysis (PCA), Correlation Matrix (CM), Factor Analysis (FA) and Discriminant Analysis (DA), Multiple Linear Regression (MLR), Analysis of Variance (ANOVA) and Water Quality Indices (WQI) etc. have been found useful in explaining spatial and temporal trends in water quality data. Some recent successful studies using multivariate techniques include the work of (Miyittah *et al*. 2020; Cavalcante *et al*, 2021; El Zrelli *et al*, 2021; Valentini *et al*., 2021). These researchers have shown that multivariate statistical approaches can be used to reduce the dimensions of the data, highlight statistically significant variables underlying variations in water quality, assess the relationship between variables and identify the sources of pollution of these waters etc. Given the urgency and necessity of producing drinking water for the population of Abidjan from the Adjin lagoon, it is important to determine the chemical quality of the water in the Adjin lagoon, to use statistical tools to assess seasonal and spatial variation and to determine the extent of pollution or sources of pollution.

2. Materials and methods

2.1. Study area

The Adjin Lagoon is an inland lagoon located on the northern shore of the Erie Lagoon system with an area of 20.2 km^2, or 3.57% of the surface of the Erie Lagoon. It is located between 588 000 m and 606 000 m North latitude, and between 3396 000 m and 414 000 m West longitude (Figure 1). It is inclined at an angle of about 30° to the coastline. The transitional equatorial climate characterises the area with a long rainy season (March-July) and a long dry season (December-February) alternating with a short rainy season (August) and a short dry season (September-November) (N'Guessan, 2008). Annual rainfall varies from 1 441 to 2 494 mm per year and Adjin's low turnover rate depends exclusively on rainfall. It receives freshwater mainly from the Djibi and Bété rivers and secondarily from the Mé river.

These three rivers influence it with respective catchment areas of 205 km^2, 85 km^2 and 4 155 km^2. Its depth varies from 1 to 14 m and can reach 20 m at the outlet of the Mé (N'Guessan, 2008). The banks of the Adjin lagoon are occupied by oil palm and rubber plantations (Figure 2 a, b) and the forests of Djibi and Akandjé. Its catchment area of 72 km^2 contains urban areas that represent 15% of the total catchment area (Koffi *et al*., 2014).

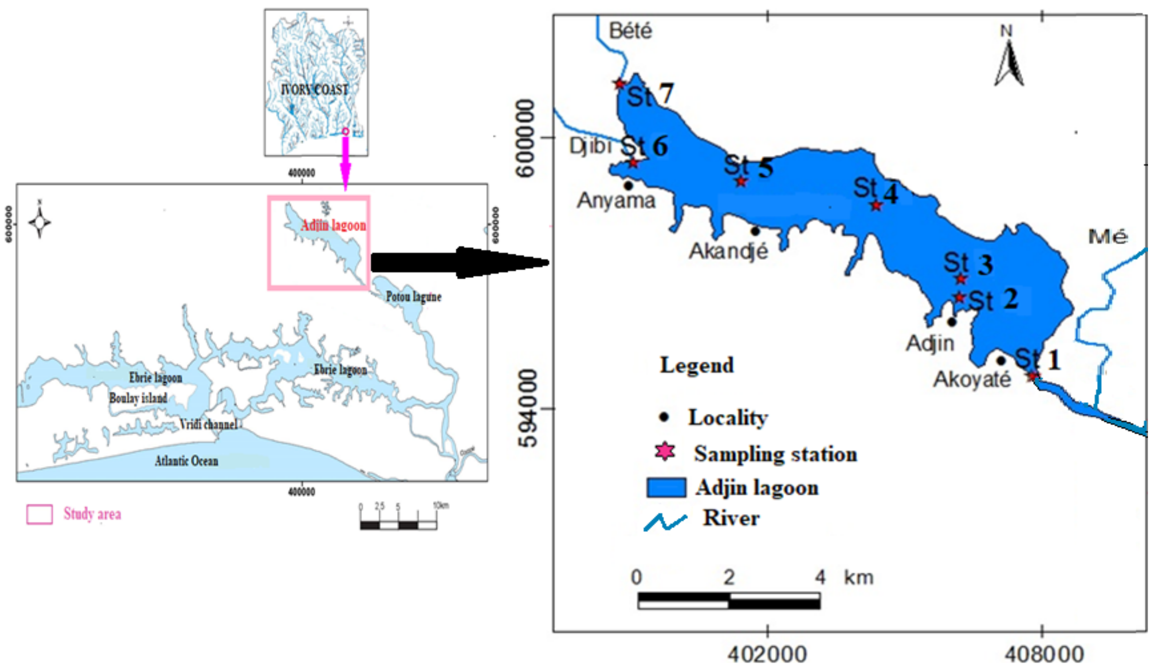

Figure 1: Location of sampling station on Adjin lagoon

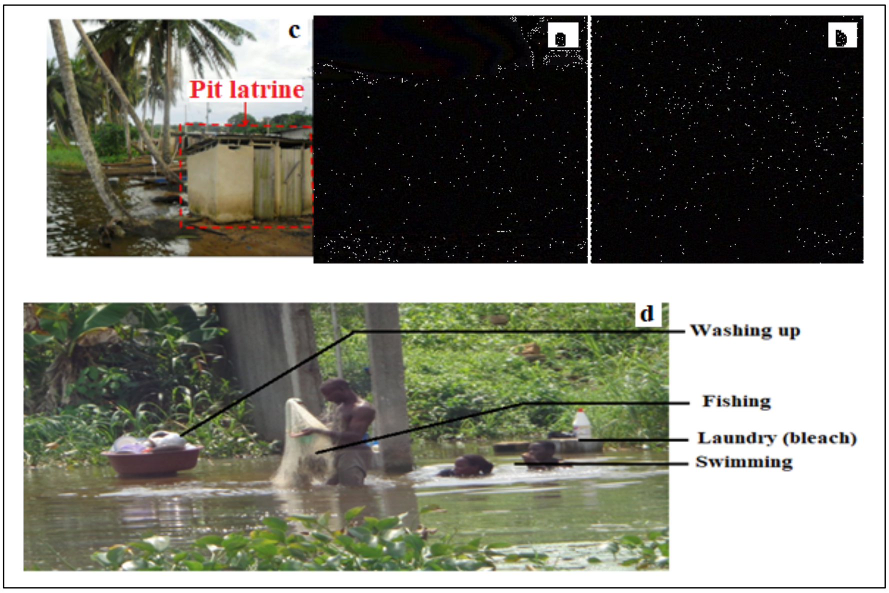

Figure 2: Industrial oil palm plantations (a), market gardening (b), pit latrine on the edge of the Adjin lagoon (c) and some activities carried out in the lagoon waters bordering Adjin village (d)

These areas include part of the commune of Abobo, Anyama, the town of Azaguié and large villages (Anyama-Débarcadaire, Adjin, Akandjé and Akouyaté) located on the banks of the lagoon. The commune of Abobo, one of the largest communes in Abidjan, is located upstream of the Adjin-Potou lagoon system with its slaughterhouse and the Abobo-Baoulé cemetery, whose wastewater reaches the lagoon via the Djibi river. These human settlements directly or indirectly discharge domestic waste (black water, household water, solid waste) into the lagoon (Figure 2 c). People living along the river directly wash their dishes and laundry in the water (Figure 2 d). In addition, the Djibi River, one of the main tributaries feeding the Adjin lagoon, still harbours toxic waste packed in bags since August 2006. This toxic waste, the chemical composition of which is still not well known, had caused the poisoning of nearly 10.000 people, several of whom died (N'Guessan, 2008).

2.2. Field sampling and analytical procedures

For water quality monitoring during the wet and dry seasons, a total of seven stations, namely (St1, St2, St3, St4, St5, St6 and St7) on the adjin lagoon were selected (Figure 1) and described (Table 1). The large and anthropised catchment area of the adjin lagoon combined with its easy access favoured the establishment of this network of sampling stations in order to cover a wide range of determinants at its sites and reasonably represent the pollution/wastewater characteristics of the study area. Seasonal sampling campaigns were conducted in November to March for the main dry season, in April to July for the main rainy season, in August for the short dry season and in September to November for the short rainy season. The samples were taken at a depth approximately 0,5 m below the surface of the water using a Niskin bottle and stored in polyethylene bottles (nutrient salts, total nitrogen, total phosphorus, COD and permanganate index) and amber glass bottles (BOD_5 and COD).

Table 1: Coordinates and descriptions of the sampling stations

Station	Latitude (m)	Longitude (m)	Note
St1	406 929	595 276	Outlet of the adjin lagoon
St 2	405 324	597 008	it receives waste from the fish feed factory and wastewater from part of the village of Adjin
St3	405 368	597 435	Fishponds of the Société Africaine de Production de Poissons on the Adjin Lagoon
St 4	403 533	599 098	In the middle of the Adjin lagoon, receives drainage water from industrial rubber and oil palm plantations, and from village plantations
St 5	400 576	599 610	It receives leachate from market gardening areas
St 6	398 202	600 036	Outlet of the Bété river
St 7	397 903	601 827	Outlet of the Djibi River, receives urban waste from a part of the Abobo commune located upstream from the Adjin lagoon

Immediately after each sampling, the samples for permanganate index, COD and Kjeldahl nitrogen analyses are acidified with concentrated sulphuric acid (98 %) to obtain a pH < 2. The water samples from all the stations were taken the same day in duplicates between 6 a.m to 10 a.m during each sampling trip per month. The samples were stored in cooling chests and transported to the Swiss Centre for Scientific Research (CSRS) and analyzed within the same day after collection.

Five physicochemical water quality parameters were measured on site: pH, temperature, electrical conductivity (EC) and dissolved oxygen (DO) were measured using multiparameter HANNA HI 9828. The turbidity was determined respectively using turbidimeter HANNA HI98703. For laboratory analyses, glass fiber filtration method (0.45 µm) was used for total suspended solids (TSS) détermination (Rodier, 2009). Spectrophotometric method of molecular absorption was used to determine nitrites (French Standard T 90 013), nitrates (French Standard T 90 012) and colorimetric method allowed the determination of ammonium (French Standard T 90 015) and orthophosphates

(French Standard T 90 023). Total phosphorus déterninatin consists of the hot mineralization of a sample in the presence of sulfuric acid and sodium persulfate followed by the spectrometric determination of the orthophosphates obtained (French Standard T90-023). The total nitrogen is obtained by french standard method (Rodier, 2009).

Permanganate index was done by the oxidability with potassium permanganate at heat, in acid medium (French Standard ISO 8467). BOD_5 is measured by the manometric method based on the WARBURG respirometer principle. That of COD is based on the mineralization with potassium dichromate and the dosage of the excess of dichromate by a solution of iron II, sulphate and ammonium in the presence of ferroïne used as indicator (French Standard T90-101). Chlorophyll *a* (chl-*a*) was determined by the monochromatic spectrometric method of Lorenzen (1967).

2.3. Data treatment and statistical analysis

First, the sample distribution of the data covered in this study was analyzed. For this, normality tests were performed. To prove or reject the normality of the data, the Kolmogorov–Smirnov (K-S) and Shapiro-Wilk (S-W) tests were used at a significance level of 0.05. For these tests, the null hypothesis (H0) considers the distribution to be normal and for p value < 0.05 this hypothesis is rejected. The K-S test is based on the largest difference between the theoretical and the empirical cumulative probabilities, in absolute value.

After the analysis of the sample distribution, for data that follows a normal distribution using locations as the factor and the measured water quality parameters as response variables, the one-way Analysis of Variance (ANOVA) was applied to examine whether the mean values of the water quality parameters varied significantly among the eight sampling stations and between different seasons. All statistical analyses were performed using STATISTICA 7.1

2.3.1. Water Quality Index

Water Quality Index (WQI) is a reliable evaluation and communication tool, useful and efficient information about the overall quality of water in a consise manner (Pradhan *et al*., 2001). The index provides a unit value that translate the overall suitability of water quality for a specific intended purpose such as drinking, irrigation or aquatic life protection and overall water quality of a certain water sample (location and time specifc) for several water quality parameters. Several indices have been successfully developed and applied for the assessment of water quality. But, the WQI developed by the Canadian Council for Ministers of the Environment (CCME WQI) has used in this study because it is not only relatively more robust but also flexible in adapting to various water quality parameters and guidelines (**CCME, 2001**). The CCME WQI value is obtained by the comparison of physico-chemical parameters against their guidelines. It relie on three factors : The Scope (F1), Frequency (F2) and Amplitude (F3) as shown in the Eq. (1) :

$$WQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right) \quad (1)$$

The denominator 1.732 standardizes the resultant WQI value to the range zero (worst quality) to 100 (best quality). The resultant vector length can reach 173.2 (Eq. (2)

$$\sqrt{100^2 + 100^2 + 100^2} = 173.2 \quad (2)$$

Thus division by 1.732 gives 100 as the maximum vector length the scope (F1) represents extent of water quality non-compliance with respect to guideline over the period of interest (Eq. (3)

$$F1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) X\ 100 \quad (3)$$

The frequency (F2) represent the proportion in percent of individual tests that are non-compliant (failed) with the respective guidelines (Eq. (4)

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ test}\right) X\ 100 \qquad (4)$$

The amplitude (F3) represents the amplitude which is the extent to which the noncompliant (failed) tests did not satisfy the respective guidelines (Eq. (5)

$$F3 = \left(\frac{NSE}{0.01NSE + 0.01}\right) \qquad (5)$$

where NSE is the Normalized Sum of Excursions which is the aggregate amount by which the individual failed tests are out of compliance of compliance (Eq. (6)

$$NSE = \frac{\sum_{i=1}^{n} excursioni}{Number\ of\ tests} \qquad (6)$$

The excursion is computed in two different ways, depending on the type of guideline. When the guideline must not be exceeded, it is computed using (Eq. (7)

$$excursioni = \left(\frac{Failed\ test\ valuei - Guideline\ valuej}{Guideline\ valuej}\right) \qquad (7)$$

And for cases where the value must not fall below the guideline, the excursion is given by Eq. (8)

$$excursioni = \left(\frac{Guideline\ valuei - Failed\ test\ valuej}{Failed\ test\ valuej}\right) \qquad (8)$$

Based on Canadian Council of Ministers of the Environment (**CCME, 2001**), the WQI values were classified into five categories and the water quality at each sampling station was categorized and interpreted according to the rating descriptions in Table 2.

Table 2: Rating description of CCME WQI[1] Scores

WQI value	Water category	Description
100 ≤ WQI ≤ 95	Excellent	All measurements are within the guidelines all the time **(does not require treatment before human consumption)**
94 ≤ WQI ≤ 80	Good	Conditions rarely depart from natural or desirable levels, **(require minor treatment works before human consumption)**
79 ≤ WQI ≤ 65	Fair	Conditions sometimes depart from natural or desirable levels, **(reasonable potable water which require advance and conventional treatment before human consumption)**
64 ≤ WQI ≤ 45	Marginal	Conditions often depart from natural or desirable levels, **(polluted water that has doubtful potable use)**
44 ≤ WQI ≤ 0	Poor	Conditions usually depart form natural or desirable levels **(highly polluted water that is unacceptable for human consumption)**

[1] : Canadian Council of Ministers of the Environment (CCME); Water Quality Index (WQI)

In this study, the WQI is calculated using the raw water quality guidelines describing in Table 3. The CCME WQI values for each sampling stations and seasons were computed using the WQI Calculator (Version 1.2, CCME). This version of the calculator is constructed in Microsoft Excel and contains a large selection of potential parameters.

Table 3: Standard limits of water quality parameters using for water quality index estimation

Parameter (unit)	Guidelines values	References
pH	6.5 - 8.5	(MSHP-MEF[1], 2020)
Turbidity (NTU)	5	(WHO, 2017)
Temperature (°C)	25	(MSHP-MEF, 2020)
Dissolved Oxygen ($mg.L^{-1}$)	5	(MSHP-MEF, 2020)
Conductivity ($\mu S.cm^{-1}$)	1000	(MSHP-MEF, 2020)
Total suspended solids ($mg.L^{-1}$)	25	(MSHP-MEF, 2020)
Ammonium ($mg.L^{-1}$)	1	(MSHP-MEF, 2020)
Nitrites ($mg.L^{-1}$)	3	(WHO, 2017)
Nitrates ($mg.L^{-1}$)	25	(MSHP-MEF, 2020)
Total nitrogen ($mg.L^{-1}$)	1.5	(Grizzetti *et al.*, 2011)
Orthophosphates ($mg.L^{-1}$)	1	(Custodio *et al.*, 2019)
Total phosphorus ($mg.L^{-1}$)	0.035 - 0.02	(Custodio *et al.*, 2019)
Permanganate index ($mg.L^{-1}$)	5	(WHO, 2017)
Chlorophyll *a* ($mg.L^{-1}$)	0.008	(Custodio *et al.*, 2019)
BOD_5 ($mg.O_2.L^{-1}$)	5	(MSHP-MEF, 2020)
COD ($mg.O_2.L^{-1}$)	30	(Custodio *et al.*, 2019)

[1]: Ministry of Health and Public Hygiene and the Ministry of Water and Forestry of Ivory Coast (**MSHP-MEF**)

2.3.2. Factor Analysis (FA)

Factor analysis is used to analyse data sets by transforming a given set of inter-related variables into a new recognizable set of variables (Mustapha and Aris, 2012 ; Miyittah *et al*., 2020). It is designed to transform the original variables into new variables called principal components (PCs), which are a combination of the original variables that are linearly related (Koklu *et al*., 2010). FA mainly analyses the interrelation between several variables in terms of their common underlying dimensions known as factors (Garizi *et al*., 2011). It provides information on the most significant parameters that describe the data set. The technique further removes the contribution of less significant variables by orthogonal rotation of the obtained axes defined by the PCs, resulting in a new set of uncorrelated PCs called Varifactors (VFs). A factor analysis was performed on the water quality data set by extracting the PCs and applying a Varimax rotation to the PCs to obtain the VFs (Miyittah *et al*., 2020).

2.3.3. Cluster analysis

Cluster analysis is an unsupervised technique that relies on the inherent structure of the data and the underlying patterns to classify objects into categories based on their similarity (Jamila *et al*., 2016 ; Miyittah *et al*., 2020). The most common approach is hierarchical clustering, which forms clusters in sequences starting with the most similar objects (Mustapha and Aris, 2012). The degree of similarity is usually based on Euclidean distances which can be explained as the difference between the values of two objects (Miyittah *et al*., 2020). Hierarchical clustering on observed water quality data was performed using Wards' method based on squared Euclidean distances between sampling stations as a measure of similarity. This method minimizes the sum of squares of possible pairs of two groups that can be formed from two clusters that can be formed at any stage. The method results in a dendrogram that displays stations with similar properties or variables as a group through rescaling.

3. Results and discussion

3.1. Physicochemical characteristics in Adjin Lagoon watter

3.1.1. Temperature, pH and dissolved oxygeen

Overall, temperature in the sampled waters ranged from 26°C (St1, St6) during the short dry season (SDS) to 34.20°C (St1, St2) during the long dry season (LDS) and the mean values ranged from 26.57 ± 0.33°C (St5; SDS) to 31.59 ± 1.55°C (St2; LDS) (Table 4). Temperature variation in Adjin Lagoon was not statistically significant seasonally [F (2.58); $p > 0.05$] and among the sampling stations [F (2.72); $p > 0.05$]. However, table values indicate that temperatures in the long dry season (February to March) are higher than those in the wet season (May to November). The high temperatures recorded in the dry period due to the high insolation could increase the rates of chemical and biochemical reactions (Groga, 2012). Water temperature may therefore be influenced by the natural climatic conditions of the area. Water temperature has considerable importance for aquatic ecosystems as it influences the reproduction and metabolism of many aquatic organisms and causes variations in most physicochemical variables of the water body. Then, it may directly affect the state of the ecosystem, limit the distribution of the plankton community, and act as a limiting factor (Cavalcante *et al*., 2012; Jakimavičius *et al*., 2018).

The minimum and maximum values of pH were 5.2 and 9.89 and were respectively observed during the short dry season (SDS) and long raining season (LRS) at station one (St1). pH average values per station ranged from 6.53 ± 0.7 (St3; SDS) to 7.44 ± 0.34 (St4; LDS) (Table 4). These waters show a weakly acidic to weakly basic character. Based on the one-way ANOVA test, the distribution of pH did not vary significantly among the sampling stations (F (2.72); $p > 0.05$). However, the variation in mean pH values per season is significantly marked within station 1 only [F (5.55); $p = 0.011$]. The mean pH of the water is higher during the long dry season (7.26 ± 0.43) than during the other seasons. Overall, the highest mean pH values are observed during the long dry season in the period from February to April, while the lowest values are recorded during the rainy period. The concentration of dissolved oxygen fluctuates between 3.77 $mg.L^{-1}$ (St1; LRS) and 9.78 $mg.L^{-1}$ (St6; LDS) (Table 4). The average dissolved oxygen concentrations per station over the entire lagoon system vary from 6.70 ± 0.9 $mg.L^{-1}$ (St3; LRS) to 8.52 ± 0.99 $mg.L^{-1}$ (St6; LDS). The table shows that within station 2, the waters are significantly more oxygenated ($p < 0.05$) during the long dry season than during the other seasons. The low concentrations are observed during the months of June and October corresponding to the rainy seasons. The high pH and dissolved oxygen values could be due to the high temperature values that stimulate photosynthetic activity during this season in the lagoons (Akinde and Obire, 2011). In Adjin lagoon, the relatively high pH and dissolved oxygen values during the dry season may be due to the low turnover rate of this lagoon. This stability of the water column leads to the trapping of nutrient salts which are then spread into the environment, which would favour the proliferation of micro-algae. Consequently, the production of dissolved oxygen and the consumption of CO_2 by these aquatic plants would favour an increase in pH and dissolved oxygen (Iltis, 1984).

3.1.2. Turbidity, total suspended solids and conductivity

The turbidity and TSS values per station vary respectively between 1.89 NTU (St6) and 49.14 NTU (St1) and between 1 $mg.L^{-1}$ (St5) and 36.5 $mg.L^{-1}$ (St1) (Table 4). The seasonal average values per station vary between 10.09 ± 5.31 NTU (St6; LDS) and 39.10 ± 9.16 NTU (St1; SRS) for turbidity and between 3.7 ± 2.51 $mg.L^{-1}$ (St7; LDS) and 23.37 ± 12.68 $mg.L^{-1}$ (St1; SDS) for SS. The turbidity and TSS values recorded during the study period have a similar evolution, in agreement with the seasonal division of the study area. Generally, rain season has significantly higher turbidity and TSS values ($p < 0.05$) than the long dry season.

Table 4. **Statistical summary of physicochemical parameters in Adjin lagoon water**

Station	Season	Temperature (°C)		pH		Turbidity (NTU)		Conductivity (µS.cm^{-1})		Total suspended solids (mg.L^{-1})		Dissolved Oxygen (mg.L^{-1})	
		Min-Max	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**
St1	**LDS**	28.40-34.20	30.22± 1.60	6.45-8.20	7.26 ±0.43	10.20-34.82	19.04±10.38	57.00-79.90	71.44±9.06	6.33-10.89	8.90±1.85	6.15-9.78	8.05±0.99
	LRS	26.70-31.24	29.11± 1.70	5.58-8.99	6.69 ±0.64	6.13-40.90	24.90±12.21	46.00-72.10	59.70 ±10.54	10.25-36.50	19.06±9.83	3.77-8.93	7.03±1.20
	SDS	26.00-30.27	27.23±1.18	6.16-6.92	6.61±0.23	31.40-44.60	38.00±9.33	46.22-65.00	55.61±13.28	14.40-32.33	23.37±12.68	4.60-8.84	7.32±1.23
	SRS	27.11-32.29	29.14±1.11	5.20-7.57	6.59±0.48	31.30-49.14	39.10±9.16	44.40-60.00	49.56±7.25	11.67-19.00	15.18±3.28	4.47-9.08	7.44±0.86
St2	**LDS**	30.20-34.20	31.59±1.55	6.81-7.89	7.33±0.42	5.10-16.04	8.61±4.62	66.00-81.00	72.19±6.32	1.67-11.00	5.83±3.56	7.00-8.91	8.26±0.76
	LRS	27.10-31.24	29.34±1.74	6.17-8.99	6.83±1.08	5.15-34.80	17.17±10.09	46.31-65.00	57.79±8.31	6.00-13.75	8.37±2.86	5.64-8.27	7.29±1.08
	SDS	26.79-29.31	27.90±1.29	6.28-6.84	6.63±0.31	6.48-31.15	18.91±12.34	58.72-67.00	62.91±4.14	4.40-11.25	7.22±3.58	6.02-7.60	6.97±0.84
	SRS	29.20-32.29	30.75±1.55	6.43-7.57	6.94±0.58	6.93-30.73	18.86±11.90	45.90-48.40	46.77±1.42	11.56-35.71	20.65±13.14	7.06-9.08	7.80±1.11
St3	**LDS**	28.56-33.20	30.02±1.88	6.45-7.83	7.20±0.52	3.45-17.90	10.42±5.36	64.00-80.00	72.02±6.44	2.80-15.00	7.40±4.65	6.42-8.15	7.33±0.65
	LRS	27.10-31.20	29.16±1.78	6.17-7.40	6.72±0.49	8.70-31.10	18.71±8.41	49.50-68.00	59.47±7.54	5.75-23.60	14.57±6.79	5.68-7.67	6.70±0.90
	SDS	26.62-26.90	26.76±0.20	6.469-6.5	6.53±0.09	11.90-28.11	20.01±11.46	57.40-76.00	66.70±13.15	4.40-8.40	6.40±2.83	6.30-8.37	7.34±1.46
	SRS	28.72-29.51	29.14±0.34	5.44-7.08	6.43±0.70	18.55-47.40	34.45±12.66	30.75-66.00	46.79±14.51	8.00-35.00	22.50±13.53	6.97-7.92	7.29±0.43
St4	**LDS**	28.97-33.20	30.45±1.61	6.94-7.82	7.44±0.34	6.33-41.90	15.61±14.83	64.00-114.00	94.32±20.32	2.33-8.60	6.01±2.86	6.19-9.18	8.03±1.22
	LRS	27.10-31.20	29.33±1.87	6.02-8.31	6.76±0.80	10.18-41.90	20.63±11.38	51.00-85.65	67.12±16.74	5.20-13.00	7.37±2.99	5.85-8.42	7.12±1.04
	SDS	26.77-29.11	27.56±1.34	6.16-6.92	6.62±0.40	7.41-16.27	12.99±4.86	57.52-78.00	65.84±10.77	4.46-13.25	7.90±4.69	6.41-8.78	7.39±1.24
	SRS	29.08-29.20	29.14±0.06	6.12-6.93	6.53±0.41	9.55-21.66	14.87±6.19	44.10-48.05	45.58 ±2.15	6.60-11.50	8.90±2.46	7.08-8.50	7.78±0.71
St5	**LDS**	28.48-32.60	29.85±1.61	6.56-7.60	7.14±0.41	4.01-13.00	9.67±3.37	81.00-120.00	101.68±16.50	1.00-10.20	4.71±4.50	6.61-9.51	8.14±1.13
	LRS	26.70-31.10	29.03±1.89	6.02-7.62	6.84±0.61	1.89-30.95	13.71±9.78	53.00-82.25	62.66±10.77	4.25-12.40	6.50±2.99	5.92-7.74	7.07±0.78
	SDS	26.30-26.84	26.57±0.38	6.33-6.89	6.61±0.40	9.60-32.60	21.10±16.26	59.00-79.00	69.00±14.14	3.60-4.71	4.16±0.79	5.91-8.84	7.38±2.07
	SRS	28.00-29.47	29.01±0.68	6.64-6.93	6.78±0.15	6.13-25.60	18.74±8.83	44.20-61.00	49.63±7.93	6.80-12.67	9.45±2.42	6.42-8.27	7.26±0.81
St6	**LDS**	28.85-32.30	29.80±1.43	6.66-7.89	7.27±0.48	4.66-15.80	10.09±5.31	67.10-159.00	104.58±37.94	3.60-8.20	6.52±1.95	7.17-9.78	8.52±0.99
	LRS	26.75-30.80	28.9±1.77	6.09-7.76	6.74±0.62	7.65-34.34	15.17±9.92	54.00-104.00	67.35±18.35	6.33-20.29	11.52±5.60	4.88-8.60	7.03±1.47
	SDS	26.00-30.27	27.69±2.27	6.52-6.90	6.71±0.19	7.05-19.41	12.35±6.36	49.00-80.00	63.33±15.63	5.60-13.70	8.99±4.21	7.65-8.38	8.00±0.37
	SRS	27.80-30.07	29.19±1.22	6.33-7.01	6.68±0.34	23.20-27.61	24.84±2.41	34.20-64.00	47.40±15.19	8.17-14.33	11.10±3.09	7.48-8.35	7.83±0.46
St7	**LDS**	28.83-32.60	30.09±1.47	6.75-7.71	7.09±0.38	2.05-20.50	9.15±7.07	66.80-155.00	98.40 ±37.65	1.37-7.56	3.71±2.51	7.71-9.14	8.49±0.63
	LRS	27.05-30.90	29.04±1.94	5.58-7.08	6.49±0.61	3.43-37.00	16.59±12.18	38.00-96.00	65.17±19.86	7.50-20.00	12.47±4.69	5.58-8.63	7.32±1.28
	SDS	26.70-26.74	26.72±0.03	6.38-6.69	6.54±0.22	9.68-16.10	12.89±4.54	59.50-79.00	69.25±13.79	5.67-7.20	6.43±1.08	6.35-8.35	7.35±1.41
	SRS	29.10-30.07	29.63±0.40	6.52-6.90	6.75±0.17	8.18-21.26	16.81±5.87	43.90-61.00	49.25±8.01	4.80-12.25	8.14±3.20	7.01-8.14	7.55±0.50

St : Station ; LDS : Long Dry Season ; LRS : Long Rainy Season ; SDS : Short Dry Season ; SRS : Short Rainy Season ; Min : minimum ; Max : maximum

During this period, rainfall will result in a higher amount of suspended solids due to the transport of organic and mineral particles in the lagoons. These suspended particles considerably reduce the transparency and increase the turbidity of the water. This observation was also made by Yao (2009) in the waters of the Ebrié Lagoon. As high levels of turbidity indicate the accumulation of sediments inside the lagoons and reduction of water volume, which in turn, will affect the dilution efficiency of the system (Cavalcante *et al*., 2021). Conductivity values vary between 30.75 µS.cm^{-1} (St3; SRS) and 159 µS.cm^{-1} (St3; LDS). The mean conductivities of the waters range from 45.58 ± 2.5 µS.cm^{-1} (St4; SRS) to 101.68 ±16.5 µS.cm^{-1} (St5; LDS) (Table 4). The waters are on the whole poorly mineralised. The same results were obtained by Yao *et al*. (2009) in the Ivorian Ebrié lagoon systems. The waters (St1, St2, St4, St5 and St6) are significantly (ANOVA, $p < 0.05$) more mineralised in the dry season than in the rainy season. The highest values are obtained in February. This parameter does not vary significantly (ANOVA, $p > 0.05$) between the study stations.

3.1.3. Nitrogen and phosphorus nutrients

Nitrite has the lowest concentrations for all forms of nitrogen assessed in Adjin Lagoons waters (Table 5). These concentrations vary from 0.001 mg.L^{-1} (St1; LDS) to 0.009 mg.L^{-1} (St7; SRS) with averages varying between 0.001 ± 0.001 mg.L^{-1} (St1; LDS) and 0.005 ± 0.003 mg.L^{-1} (St7; SRS). For ammonium, nitrate and total nitrogen, the average concentrations per station for ammonium ranged from 0.006 ± 0.004 mg.L^{-1} (St2; LDS) to 0.071 ± 0.040 mg.L^{-1} (St6; LRS) and those of nitrates and total nitrogen are respectively between 0.71 ± 0.4 mg.L^{-1} (St1; LDS) and 4.95 ± 0.98 mg.L^{-1} (St6; LRS) and between 0.97 ± 0.13 mg.L^{-1} (St7; LRS) and 2.68 ± 1.3 mg.L^{-1} (St6; LRS). Temporally, the concentrations of nitrites (St1 and St2), ammonium (St2, St4, St5, St6 and St7), nitrates (St1, St2 and St3) and total nitrogen (St1, St2, St3 and St6) in the rainy season are significantly higher ($p < 0.05$) than those in the long dry season. For different forms of phosphorus (orthophosphates and total phosphorus) assessed in the water (Table 5), the averages per station during the study period ranged from 0.02 ± 0.01 mg.L^{-1} (St1; LDS) and 0.08 ± 0.02 mg.L^{-1} (St5; SDS) for orthophosphates and 0.04 ± 0.02 mg.L^{-1} (St1; LRS) and 0.19 ± 0.11 mg.L^{-1} (St2; LDS) for total phosphorus.

At stations St1, St2, St4, St6 and St7 for orthophosphate and at stations St2, St3, St4, St5 and St6 for total phosphorus, the waters of the long dry season are significantly ($p < 0.05$) less loaded with orthophosphates and phosphorus than those of the rainy period. The nutrient richness of the Adjin lagoons is mainly related to rainfall and the massive changes resulting from human activities (Mezhoud *et al*., 2016; Edmonds *et al*., 2021) from villages located on the edge of the lagoon and the communes of Abobo and Anyama (St6, St7).

3.1.4. Chlorophyll *a*, permanganate index, DOC and BOD$_5$

Chlorophyll-a values during the study period per station ranged from 24.03 µg.L^{-1} (St4; LDS) to 80.69 µg.L^{-1} (St7; SDS). As for the average concentrations, they vary from 34.64 ± 4.83 µg.L^{-1} (St7; LDS) to 69.4 ± 15.34 µg.L^{-1} (St7; LDS) (Table 6). Chlorophyll *a* data were used to classify the trophic levels in the lagoons according to the most widely accepted limits suggested by the Organization for Economic Cooperation and Development (e.i, oligotrophic state, chl-*a* < 2.5 µg.L^{-1} ; mesotrophic, 2.5 < chl-*a* < 8 µg/L; eutrophic chl-*a* > 8 µg.L^{-1}) (Istvánovics, 2009). With this chl-*a* values, adjin lagoon is an eutrophic condition which is an important finding considering eutrophication has been one of the main global threat to the quality of water resources (Istvánovics, 2009), and especially in a hot climate such. Seasonally, the waters of Adjin Lagoon have significantly higher chlorophyll *a* concentration ($p < 0.05$) in the main rainy season than in the dry season at stations St2, St3 and St6.

Table .5. Satistical summary of nutrients in Adjin lagoon water

Station	Season	Ammonium ($mg.L^{-1}$)		Nitrites ($mg.L^{-1}$)		Nitrates ($mg.L^{-1}$)		Total nitrogen ($mg.L^{-1}$)		Total phosphorus ($mg.L^{-1}$)		Orthophosphates ($mg.L^{-1}$)	
		Min-Max	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**	**Min-Max**	**Mean ± S**
St1	LDS	0.00-0.04	0.01±0.01	0.00-0.003	0.001±0.001	1.08-2.08	1.54±0.44	0.42-2.61	1.0 ±80.44	0.01-0.10	0.0±5±0.02	0.00-0.07	0.03±0.02
	LRS	0.01-0.13	0.06±0.03	0.002-0.005	0.003±0.001	2.74-4.33	3.43±0.59	0.95-4.35	2.13 ±0.79	0.06-0.37	0.15±0.06	0.00-0.10	0.06±0.03
	SDS	0.00-0.16	0.06±0.04	0.002-0.004	0.003±0.001	2.45-3.82	3.13±0.96	0.92-2.60	1.47±0.47	0.10-0.16	0.13±0.02	0.03-0.07	0.05±0.01
	SRS	0.03-0.11	0.06±0.02	0.002-0.005	0.003±0.001	3.74-5.94	4.95 ±0.98	0.74-3.24	1.95±0.70	0.10-0.36	0.17±0.06	0.04-0.10	0.07±0.02
St2	LDS	0.001-0.012	0.006±0.005	0.001-0.002	0.002±0.001	0.42-2.76	1.10±0.96	0.62-1.59	1.07±0.38	0.04-0.09	0.06±0.02	0.01-0.07	0.04±0.02
	LRS	0.015-0.084	0.048±0.029	0.002-0.004	0.003±0.001	1.85-5.21	3.10±1.49	1.54-3.02	2.02±0.57	0.10-0.25	0.18±0.07	0.05-0.10	0.07±0.02
	SDS	0.013-0.074	0.047±0.031	0.002-0.002	0.002±0.000	2.10-2.49	2.35±0.22	1.14-1.92	1.65±0.44	0.13-0.16	0.14±0.01	0.05-0.07	0.06±0.01
	SRS	0.033-0.053	0.046±0.011	0.001-0.002	0.002±0.001	1.16-1.87	1.53±0.35	1.26-1.59	1.45±0.17	0.13-0.19	0.16±0.03	0.06-0.09	0.08±0.02
St3	LDS	0.002-0.02	0.008±0.006	0.001-0.002	0.001±0.000	0.67-2.14	1.38±0.58	0.85-1.17	0.97±0.13	0.02-0.07	0.04±0.02	0.01-0.04	0.02±0.01
	LRS	0.010-0.079	0.053±0.026	0.001-0.003	0.002±0.001	1.51-3.28	2.17±0.81	0.95-2.62	1.91±0.65	0.10-0.28	0.17±0.06	0.00-0.10	0.04±0.04
	SDS	0.048-0.079	0.064±0.022	0.001-0.002	0.002±0.000	1.85-2.00	1.93±0.11	0.92-1.32	1.12±0.28	0.11-0.14	0.12±0.02	0.03-0.05	0.04±0.01
	SRS	0.037-0.086	0.063±0.020	0.001-0.002	0.001±0.001	2.93-5.23	4.20±1.06	1.62-2.63	2.10±0.46	0.11-0.24	0.16±0.06	0.05-0.07	0.06±0.01
St4	LDS	0.004-0.015	0.010±0.006	0.00-0.002	0.001±0.001	0.40-1.66	0.86±0.57	0.51-1.55	0.98±0.40	0.01-0.07	0.05±0.03	0.01-0.04	0.02±0.01
	LRS	0.023-0.073	0.052±0.022	0.001-0.003	0.002±0.001	0.54-3.81	2.28±1.22	1.05-2.41	1.63±0.56	0.08-0.17	0.13±0.03	0.01-0.09	0.05±0.03
	SDS	0.001-0.072	0.043±0.037	0.001-0.002	0.002±0.000	1.38-2.18	1.89±0.44	0.98-2.60	1.68±0.83	0.11-0.15	0.13±0.02	0.03-0.06	0.04±0.01
	SRS	0.026-0.100	0.069±0.038	0.001-0.002	0.002±0.000	1.61-5.20	2.98±1.94	0.86-1.97	1.30±0.59	0.14-0.16	0.15±0.01	0.04-0.06	0.05±0.01
St5	LDS	0.002-0.040	0.017±0.014	0.00-0.003	0.001±0.001	0.48-5.20	1.74±1.96	0.42-2.61	1.45±0.87	0.01-0.10	0.05±0.03	0.01-0.04	0.02±0.01
	LRS	0.014-0.116	0.063±0.037	0.001-0.005	0.003±0.001	1.45-5.26	3.51±1.56	1.53-4.35	2.68±1.23	0.06-0.16	0.13±0.04	0.03-0.10	0.06±0.03
	SDS	0.046-0.075	0.061±0.021	0.002-0.002	0.002±0.000	1.75-1.84	1.79±0.06	0.92-1.95	1.44±0.73	0.11-0.15	0.13±0.02	0.03-0.04	0.04±0.01
St6	LDS	0.002-0.040	0.019±0.015	0.00-0.002	0.001±0.001	0.18-1.21	0.71±0.40	0.43-1.37	0.99±0.37	0.01-0.08	0.06±0.03	0.01-0.03	0.02±0.01
	LRS	0.012-0.132	0.071±0.041	0.001-0.004	0.003±0.001	1.30-5.01	3.19±1.25	0.95-3.17	2.21±0.85	0.10-0.17	0.12±0.03	0.04-0.10	0.06±0.02
	SDS	0.031-0.081	0.055±0.025	0.001-0.002	0.001±0.001	1.71-3.05	2.23±0.72	1.11-1.65	1.46±0.30	0.10-0.15	0.13±0.03	0.04-0.07	0.05±0.01
	SRS	0.032-0.059	0.044±0.014	0.001-0.003	0.002±0.001	1.60-2.42	1.99±0.42	0.84-2.30	1.60±0.73	0.10-0.17	0.14±0.03	0.05-0.09	0.07±0.02
St7	LDS	0.003-0.030	0.015±0.009	0.000-0.003	0.001±0.001	0.48-3.72	1.69±1.22	0.70-1.63	1.13±0.35	0.02-0.07	0.05±0.02	0.01-0.04	0.03±0.01
	LRS	0.014-0.094	0.059±0.033	0.001-0.004	0.002±0.001	1.46-5.79	2.85±1.59	1.00-2.93	1.97±0.70	0.07-0.16	0.12±0.04	0.02-0.10	0.05±0.03
	SDS	0.033-0.078	0.056±0.032	0.001-0.002	0.002±0.001	2.37-2.42	2.39±0.03	1.11-1.66	1.38±0.39	0.11-0.12	0.12±0.00	0.04-0.05	0.04±0.01
	SRS	0.029-0.060	0.048±0.014	0.002-0.009	0.005±0.003	1.86-6.91	4.20±2.33	1.60-2.74	2.08±0.50	0.12-0.18	0.15±0.03	0.06-0.08	0.06±0.05

St : Station ; LDS : Long Dry Season ; LRS : Long Rainy Season ; SDS : Short Dry Season ; SRS : Short Rainy Season , Min : minimum ; Max : maximum

Permanganate index (PI) average values per station ranged from 5.82 ± 0.94 $mg.L^{-1}$ (St7; LDS) to 15.65 ± 5.17 $mg.L^{-1}$ (St7; LRS). The PI values are significantly higher ($p < 0.05$) during the rainy seasons than during the dry seasons at the St4, St6 and St7 stations. Spatially, the minimum (4.23 $mg.L^{-1}$) and maximum (21.51 $mg.L^{-1}$) values were recorded at stations St3, St6 and St7 respectively (Table 6). The COD measured during the sampling period varies from 37 mg $O_2.L^{-1}$ at station St2 to 247.1 mg $O_2.L^{-1}$ at station St4. The average value recorded varies from 147.35 ± 55.05 mg $O_2.L^{-1}$ (St2) to 81.76 ± 33.04 mg $O_2.L^{-1}$ (St4). As for BOD_5, it varies between 2.91 mg $O_2.L^{-1}$ at station St4 and 105.78 mg $O_2.L^{-1}$ at station St3. The average value of the latter is between 7.35 ± 4.34 mg $O_2.L^{-1}$ (St4; SRS) and 59.79 ± 31.62 mg $O_2.L^{-1}$ (St6; LRS) (Table 6). The variation in COD and BOD_5 is not marked between the sampling sites. The seasonal variation per site is sometimes very significant ($p < 0.05$) between the rainy period and the long dry season. For all stations except St4, the BOD_5 values of the long dry season are lower than those of the long rainy season. For COD, only the average values of stations St2 and St3 remain higher during the wet season. The higher values of the organic matter parameters (permanganate index, COD and BOD_5) recorded in the rainy season indicate that most of the organic pollutants are washed out of the lagoon system by stormwater runoff.

3.2 Water quality index

The water quality in the Adjin lagoon during the study period can be classified as poor (WQI score: 44.52) according to the CCME water quality index (Tab.7) because during the long rainy season (WQI score: 42.4), the short rainy season (WQI score: 43.88) and the dry season (WQI score: 44.33), the water quality is poor. However, in the long dry season, the water quality is considered marginal (WQI score: 47.7). The marginal score according to CCME (2001) indicates that the water quality variables often deviate from the MSHP-MEF (2020) guidelines for domestic use and protection of aquatic life. Thus, water quality may not be suitable for domestic use and may not sustainably support aquatic organisms. The marginal quality of the waters of the Aby Lagoon were obtained by Miyittah *et al*. (2020) in Ghana. Furthermore, the waters from the seven sampling stations all fall within the range of poor-quality water as well (WQI < 44) (Table 8). The WQI results indicate a relatively homogeneous water quality in the lagoon. This poor water quality is related to the non-compliance of turbidity, dissolved oxygen and organic parameters with the MSHP-MEF (2020) guidelines.

3.3. Factor and cluster analysis of water quality

In order, to identify the main factors influencing water quality variations at the different stations, data were subjected to factor and cluster analysis. The results of the factor analysis presented in the table 9 indicate that the extraction of the factors resulted in three PCs with eigenvalues >1 that account for 57.33% of the total variability of the observed water quality data set. The first Varifactor, VF1, accounted for 43.45% of the overall variance of the water quality data. This factor showed a strong positive loading on total phosphorus, permanganate index, COD and BOD_5 but a negative loading on conductivity and suspended solids. The second factor, VF2, showed a strong positive loading on total nitrogen and negative loadings on temperature and dissolved oxygen. The factor VF2 explained 7.20% of the total variance in water quality data. VF3 shows a strong positive loading and explains 6.68% of the total variance in water quality data.

Table.6. Statistical summary of organic parameters of Adjin lagoon water

Station	Season	Chlorophyll *a* ($\mu g.L^{-1}$)		Permanganate index ($mg.L^{-1}$)		COD ($mgO_2.L^{-1}$)		BOD_5 ($mgO_2.L^{-1}$)	
		Min-Max	Mean ± S	Min-Max	Mean ± S	Min-Max	Mean ± S	Min-Max	Mean ± S
St1	LDS	27.67-80.69	53.08±15.51	4.23-14.40	8.15±2.58	51.28-92.90	64.39±17.14	5.20-17.63	14.24±5.25
	LRS	30.24-68.65	47.19±9.24	4.97-16.56	11.49±2.56	89.18-218.08	131.43±47.83	15.30-76.22	50.76±27.59
	SDS	24.03-74.76	43.87±11.56	8.25-12.29	10.03±1.20	58.40-105.12	81.76±33.04	19.7-22.00	20.87±1.59
	SRS	27.44-54.77	37.83±6.65	6.06-21.51	11.51±3.63	63.57-218.72	136.36±71.64	25.30-66.05	38.20±18.78
St2	LDS	42.72-63.96	54.30±8.53	5.95-12.02	8.39±2.24	42.00-131.13	75.41±34.00	8.06-16.00	11.23±3.31
	LRS	33.76-61.91	51.90±10.00	9.38-14.26	12.24±1.90	74.56-205.92	131.03±47.05	18.30-103.70	59.79±31.62
	SDS	33.15-48.20	39.33±7.88	10.17-12.29	11.01±1.13	70.48-112.09	88.87±21.22	30.93-45.00	36.57±7.44
	SRS	31.70-40.56	36.46±4.47	11.13-11.95	11.40±0.48	88.76-198.00	147.35±55.05	36.70-46.00	41.70±4.69
St3	LDS	34.18-58.83	48.02±11.02	8.08-12.96	10.53±2.03	59.35-99.15	82.98±15.60	13.48-23.48	17.88±3.72
	LRS	47.15-68.65	53.01±8.14	10.49-15.61	12.72±1.88	92.30-187.65	140.28±36.66	26.29-105.78	58.28±30.43
	SDS	42.8552.07	47.46±6.52	8.41-11.06	9.74±1.87	87.14-91.60	89.37±3.16	35.00-41.17	38.09±4.37
	SRS	27.44-37.78	34.64±4.83	7.42-19.04	13.50±4.78	98.80-156.80	122.96±27.63	42.03-64.37	51.34±9.38
St4	LDS	32.12-66.22	49.68±12.30	5.88-10.12	7.87±1.70	41.30-83.70	55.80±17.17	4.45-13.60	9.29±3.40
	LRS	37.66-62.76	50.88±9.12	7.74-12.13	9.67±1.68	65.62-205.92	120.43±49.37	10.90-73.56	40.94±24.34
	SDS	31.45-53.40	42.35±10.97	8.25-9.03	8.58±0.40	60.87-146.00	101.93±42.65	10.00-38.51	23.85±14.27
	SRS	33.81-51.64	41.35±9.23	7.94-9.54	8.87±0.83	70.52-170.72	126.41±51.10	36.60-62.00	47.93±12.92
St5	LDS	27.67-80.69	47.72±19.83	6.99-11.18	8.79±1.83	37.19-111.70	73.01±28.20	6.66-17.63	12.99±4.78
	LRS	30.78-54.29	39.76±8.77	10.54-14.87	12.41±1.61	52.16-163.68	111.47±42.14	21.55-62.00	41.57±19.88
	SDS	38.72-44.98	41.85±4.43	9.74-10.03	9.89±0.20	58.80-91.76	75.28±23.30	20.00-22.71	21.36±1.92
	SRS	27.53-41.04	34.94±6.18	11.39-14.59	12.60±1.52	67.77-184.32	126.70±48.01	22.81-48.22	36.26±10.91
St6	LDS	43.06-79.95	69.40±15.34	4.69-7.07	5.82±0.94	47.63-91.48	77.64±17.63	5.60-12.24	9.54±3.09
	LRS	39.90-55.28	49.28±5.97	8.12-16.56	11.32±3.03	64.96-150.55	108.32±34.12	15.23-56.44	41.84±20.13
	SDS	32.57-74.76	50.24±21.91	8.80-11.70	10.24±1.45	78.35-117.52	95.56±20.01	26.00-67.92	41.85±22.75
	SRS	27.44-40.30	35.85±7.29	11.73-21.51	15.65±5.17	80.80-137.15	107.82±28.25	46.39-66.80	55.00±10.57
St7	LDS	34.13-70.51	49.82±15.36	4.23-8.97	6.03±2.03	37.00-109.00	62.19±29.88	2.91-13.48	7.35±4.34
	LRS	30.24-54.76	42.46±9.56	7.17-13.59	10.51±2.64	70.00-247.10	124.26±69.14	16.47-66.20	42.58±22.05
	SDS	44.06-49.38	46.72±3.77	9.37-10.82	10.09±1.02	45.20-113.24	79.22±48.11	27.00-28.27	27.64±0.90
	SRS	36.44-54.77	41.53±8.84	6.06-8.63	7.34±1.48	83.17-120.00	93.67±17.62	39.5391.00	58.96±22.41

St : Station ; LDS : Long Dry Season ; LRS : Long Rainy Season ; SDS : Short Dry Season ; SRS : Short Rainy Season ; Min : minimum ; Max : maximum

Table 7: CCME WQI quality classification of sampling stations in Adjin Lagoon

Seasons	WQI	Category
LDS	47.7	Marginal
LRS	42.4	Poor
SDS	44.33	Poor
SRS	43.88	Poor
Adjin lagoon	**44.52**	**Poor**

Table 8: CCME WQI quality classification of sampling stations in Adjin Lagoon

Stations	WQI	Category
St1	41.71	Poor
St2	43.49	Poor
St3	41.76	Poor
St4	41.4	Poor
St5	43.24	Poor
St6	42.78	Poor
St7	42.34	Poor
Adjin Lagoon	**42.38**	**Poor**

Table 9: Factor loadings of Varifactors (VFs) on water quality variables

Parameter	Varifactor 1	Varifactor 2	Varifactor 3
Temperature (°C)	-0.03	**-0.75**	-0.07
pH	-0.30	-0.54	-0.27
Turbidity (NTU)	0.27	0.04	**0.77**
Conductivity ($\mu S.cm^{-1}$)	**-0.64**	-0.27	-0.24
Total suspended solids ($mg.L^{-1}$)	**0.67**	0.01	0.34
Dissolved Oxygen ($mg.L^{-1}$)	-0.27	**-0.68**	-0.04
Ammonium ($mg.L^{-1}$)	0.46	0.52	0.19
Nitrites ($mg.L^{-1}$)	0.00	0.44	**0.65**
Nitrates ($mg.L^{-1}$)	0.29	0.55	0.42
Total nitrogen ($mg.L^{-1}$)	0.36	**0.60**	0.32
Total phosphorus ($mg.L^{-1}$)	**0.65**	0.43	0.28
Orthophosphates ($mg.L^{-1}$)	0.48	0.49	0.35
Chlorophyll *a* ($\mu g.L^{-1}$)	-0.43	-0.15	-0.31
Permanganate index ($mg.L^{-1}$)	**0.77**	0.16	0.00
DCO ($mgO_2.L^{-1}$)	**0.64**	0.48	-0.22
DBO_5 ($mgO_2.L^{-1}$)	**0.64**	0.42	0.30
Eigenvalues	**6.95**	**1.15**	**1.07**
% of Variance	**43.45**	**7.20**	**6.68**
Cumulative %	**43.45**	**50.65**	**57.33**

Cluster analysis of the water quality data set produced a dendrogram (Figure 3) which indicates that the seven sampling stations can be classified into three significant clusters at a combined cluster value of rescaled distance < 15. Cluster 1 comprised the upstream stations St4, St5, St6 and St7. Cluster 2 was formed by station St2 and St3 which is located in the middle. Cluster 3 included only the downstream station St1. Two-dimensional scatter plot of the average VF1 and VF2 scores for the sampling stations is presented (Figure 4). The data indicate the relative contribution of the factors to the overall water quality conditions and highlight the spatial similarity at each sampling station in terms of the water quality variables. It was observed that the VF1 variables (total phosphorus, permanganate index, COD and BOD_5, conductivity and TSS) were highest at the stations (St4, St5, St6 and St7) located upstream of the river. Indeed, the water from these stations is enriched with wastewater from the villages located on the edge of the lagoon and from the communes of Abobo and Anyama located upstream. The local populations wash their dishes and clothes and take their baths in this lagoon water.

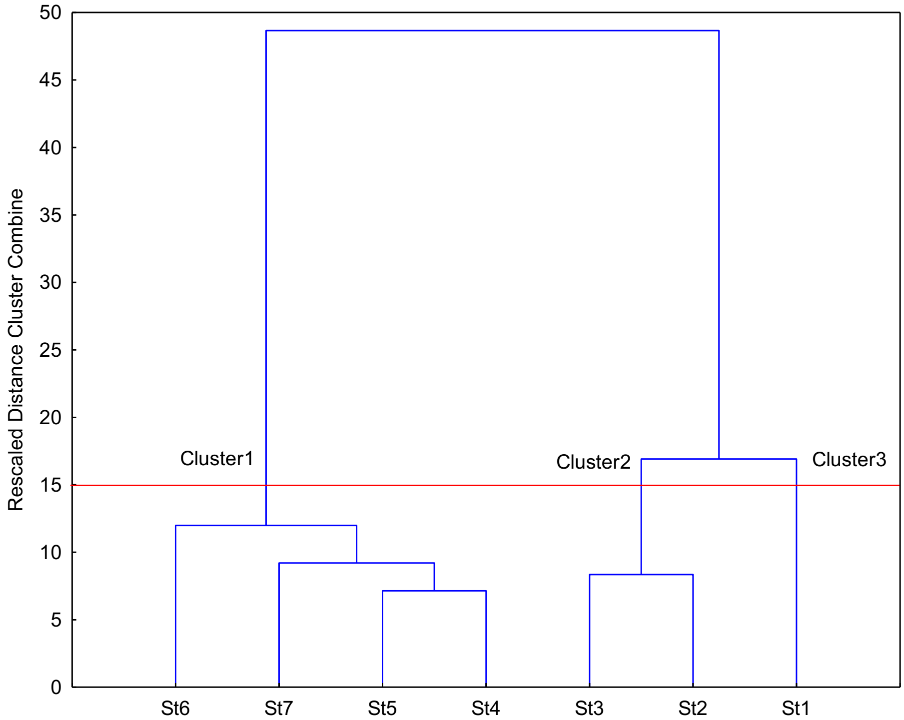

Figure 3: Dendrogram showing the clustering of sampling stations in Adjin lagoon: St1 (Station 1), St2 (Station 2), St3 (Station3), St4 (Station 4), St5 (Station 5), St6 (Station 6) and St7 (Station7)

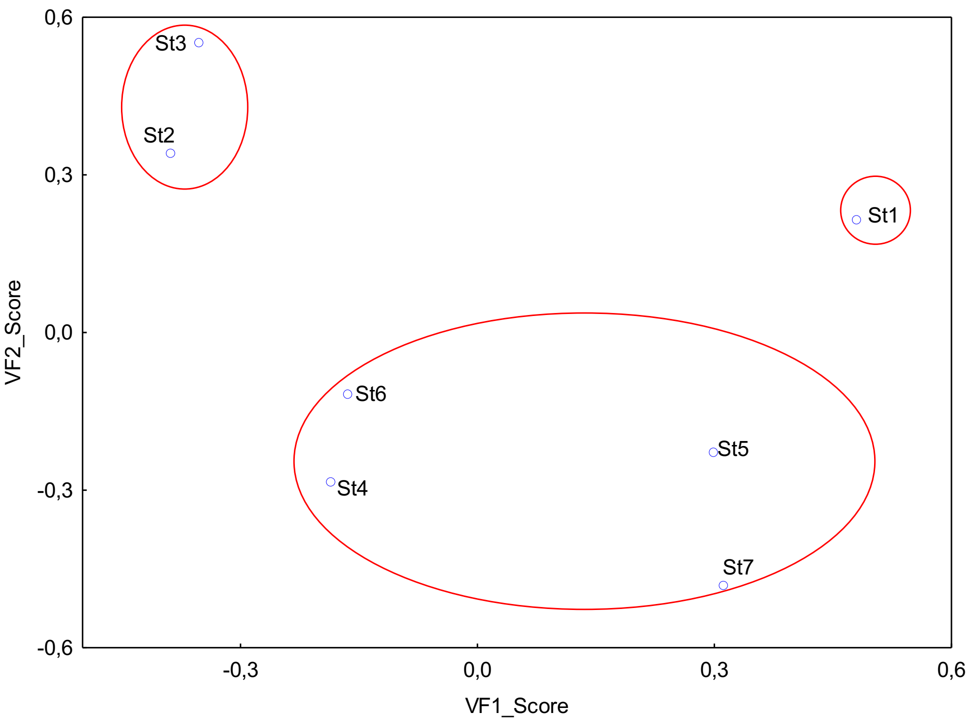

Figure 4: A scatter plot of mean scores of varifactors showing the grouping of sampling stations in Adjin lagoon: St1 (Station 1), St2 (Station 2), St3 (Station 3), St4 (Station 4), St5 (Station 5), St6 (Station 6), St7 (Station 7)

All the products used for this purpose, such as detergents, are rich in phosphorus compounds. All these pollutants are discharged directly into the lagoon without any prior treatment (Mezhoud *et al*., 2016 ; Edmonds *et al*., 2021). These stations also receive water from the Djibi and Bété rivers. Also, during the rainy season, the organic matter produced by the plant and animal debris decomposed during the dry season is carried by the run-off water into the lagoon. These high concentrations of organic matter induce a high consumption of oxygen for their degradation, which leads to the high values of oxygen demand (COD and BOD_5) observed (Yao *et al*., 2009).

VF2 (total nitrogen, temperature and dissolved oxygen) was found to be dominant in the mid-lagoon section at stations St2 and St3. The high temperature values stimulate photosynthetic activity which promotes high transparency that allows sunlight to penetrate the water column and increases its oxygenation (Akinde and Obire, 2011). The nitrogenous nutrients in these two nearby sites could have originated from the fish farm sites of station St3 corresponding to the fish farm sites of Adjin Lagoon. It is estimated that about 40% of the nitrogen in fish feed is taken up in the fish biomass, with the remainder being released to the environment as metabolic waste, excreta and uneaten food fragments (Merceron *et al*., 2002).

Group 3 records the only St1 station located downstream of the lagoon. It is characterised by VF3 (turbidity and nitrite) and records low VF1 and VF2 values. This downstream station is influenced by rainfall, which leads to a greater quantity of suspended matter due to the transport of organic and mineral particles in the lagoons. These suspended particles reduce considerably the transparency and increase the turbidity of the water (Yéo *et al*., 2014).

Conclusion

The main objective of this study was to determine the chemical quality of the water in the Adjin lagoon and to determine the extent of pollution using statistical tools. At the end of this work, it appears that the Adjin lagoon in its upstream part is subject to organic pollution (total phosphorus, permanganate index, COD and BOD_5) of anthropic origin (wastewater from the villages and communes around the lagoon). In the intermediate part, we note nitrogenous pollution linked to the fish farming practices carried out on the water body. Downstream, the waters of the lagoon are more turbid. At the temporal level, rainfall influences the quality of the water with the highest loads of pollutants recorded during the rainy season. The water quality index of Adjin indicates that the water is of poor quality at all seven stations and in every season, with the exception of the long dry season when the water quality is marginal.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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