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Type of the Paper (Original Research)

Physico-Chemical Characterization and Spatio-Temporal Variation of Water Quality in the Sô and Djonou Rivers Tributary to Lake Nokoué in West Africa

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Key Words	Water quality, physico-chemical characterization, Pollution, Lake Nokoué
DOI	https://doi.org/10.46488/NEPT.2025.v24i04.D1746 (DOI will be active only after the final publication of the paper)
Citation for the Paper	Atchichoe, W. N., Dovonou, F. E., Adandedji, F. M. and Eninhou, F. S., 2025. Physico-chemical characterization and spatio-temporal variation of water quality in the Sô and Djonou rivers tributary to lake Nokoué in West Africa. *Nature Environment and Pollution Technology*, 24(4), p. D1746. https://doi.org/10.46488/NEPT.2025.v24i04.D1746

Abstract: The aim of this study is to quantify nutrient inputs from the collection of water quality data at twelve (12) sites over a twelve-month period (January 2023 to December 2023). A total of twenty-one water pollution indicator parameters were monitored. An inventory of anthropogenic pressures on the two tributaries (Sô and Djonou) was used to define the points at which water samples would be collected in the field. Physico-chemical parameters were analysed using molecular absorption spectrometry (HACH DR 5000). TMEs were detected and quantified in the water using atomic absorption spectrometry. The results of the laboratory analyses indicate non-compliance with Benin's wastewater quality standards and

France's Environmental Quality Directives (NQE), resulting in physico-chemical pollution of the water in the two rivers. Nitrogen pollution was observed, with total nitrogen levels ranging from 0.18 to 8.25 mg/L (Djonou) and from 0.03 to 10.89 mg/L (Sô). Then there is phosphorus pollution, with total phosphorus levels ranging from 0 to 2.14 mg/L (Djonou) and from 0 to 2.45 mg/L (Sô). These two types of pollution observed resulted in algal pollution with chlorophyll a varying from 0 to 4.01 mg/L (Djonou) and from 0 to 3.36 mg/L (Sô). Cadmium (Cd) varied from 0.01 to 0.24 mg/L (Djonou) and from 0 to 0.10 mg/L (Sô) and lead (Pb) varied from 0.01 to 0.35 mg/L (Djonou) and from 0 to 0.04 mg/L (Sô). The correlation matrix and the PCA carried out on the mean annual values of the parameters reveal that in the dry season the water in the Sô and Djonou rivers is rich in Biochemical Oxygen Demand after Five Days (BOD_5), Chemical Oxygen Demand (COD) , Cadmium (Cd), Conductivity, Nitrites (NO_2^-) and Salinity, in contrast to the water in the rainy season, which is rich in Total phosphorus, Phosphates(PO_4^{2-}), Nitrogen Total (NT), Ammonium (NH_4^+) and Nitrates (NO_3^-).

These types of pollution will cause eutrophication and poisoning of fish stocks in the two tributaries. It is therefore necessary to monitor these parameters over a longer period of time in order to model water quality in these tributaries and avoid major environmental and health problems.

1. INTRODUCTION

In West Africa, south of the Sahara, there is a continuous sequence of lagoons along the Atlantic Ocean whose fishery resources are highly varied and intensively used by the local populations. Specifically, in West Africa, Lake Nokoué is richer in fish resources, with an annual yield of around one tonne per hectare compared with 290 kg per hectare per year for all the West African lakes. (Lalèyè et al. 2003). Domestic waste is discharged directly into the lake, which receives a volume of wastewater of 217 tonnes of BOD5 per year (Direction des pêches, 2004). Other sources of threat include industrial and agricultural effluents, pesticides and fishing, as well as strong saline intrusion (MAMA, 2010).

The various tributaries of Lake Nokoué are: the Ouémé, Sô and Djonou rivers. In the municipality of Sô-Ava, the pollution of Lake Nokoué and the river Sô is mainly due to defecation in nature by the population, the proliferation of household waste and other rubbish, the clogging of the lake by acadjas, the roaming of animals and the invasion of the lake by water hyacinths (SGP's, 2021). Insalubrity is also gaining ground in the immediate and immediate vicinity of the Djonou river, threatening its very existence. Solid household waste is dumped there on a daily basis, polluting the atmosphere and Lake Nokoué (Fraternité Journal, Octobre 2016). As a result, the water in the River Sô is heavily polluted from a chemical, organic and bacteriological point of view, with a high risk of faecal contamination that could lead to poisoning of people who consume fish stocks; the latter are also exposed to the risk of asphyxiation (Sériki, 2018).

Lake Nokoué and its tributaries are subject to bacteriological, chemical and organic pollution, most of which comes from human activities (Kouchade, 2002). Thus, 64% of households living near the Sô and Djonou rivers (tributaries of Lake Nokoué) do not have a sanitation system and practise open defecation; 72% of households have poor waste management; 20% of households use NPK fertiliser in agriculture and market gardening; 69% of households water their livestock directly from the river; 3% of households sell fuel, with the risk of oil products being spilt in rivers, causing heavy chemical pollution; 14.41% of households use acadja branches and products (1.80% of households) as a means of fishing; 80.7% of households suffer recurrently from malaria, chronic diarrhoea and skin infections (Atchichoe et al, 2024).

The inventory of water bodies in southern Benin (Roche International, 2000) revealed the presence of chemical, microbiological and organic pollutants in Lake Nokoué. Chemical and bacteriological agents pollute the pollution quality system of Lake Nokoué.

Several studies have been carried out on the pollution of Lake Nokoué and its tributaries but very few have studied the spatio-temporal characterisation of the various pollutants resulting from human activities in the Sô and Djonou rivers. So, in order to better appreciate the different sources of pollution in Lake Nokoué, we decided to study the pollution of two of its tributaries, which will serve as a basis for further studies to find out which of the tributaries supplies more pollution to Lake Nokoué so that the authorities at various levels can act on it to reduce pollution in Lake Nokoué..

This justifies the choice of our research topic entitled: Physico-chemical characterisation and spatio-temporal variation of water quality in the tributaries of Lake Nokoué in West Africa.

2. MATERIALS AND METHODS

2.1 Geographical location of the Sô and Djonou rivers

The Sô River is located between latitudes 6°24' and 6°38' North and longitudes 2°27' and 2°30' East, predominantly flowing along the commune of Sô-Ava (Bénin Topo-foncier, 2006). It rises in Lake Hlan and is linked to the River Ouémé by marigots (Figure 1). The Sô River is one of the former branches of the Ouémé River, which has since detached, discharging its waters to the northwest of Lake Nokoué, near the lakeside town of Ganvié (Lalèyè, 1995). The river is linked to the Ouémé River through a series of marigots. The highest flow rates occur during flood events. During these floods, the river inundates surrounding lands and enhances fish trap and *acadja* (a traditional fishing method) productivity. The Sô River has several distributary channels, all navigable during the flood period, including the Akassato, Gbéssou, and Zoungomey arms. In the northern part of the river, near the locality of Kinto, the Sô River bifurcates into two branches forming a Y-shape. The right arm leads to Adjohoun, while the left arm flows towards Kpomè in the Sèhouè locality.

The Djonou River is located between latitude 6°22’31’’ North and longitude 2°19’40’’ East (Atchichoe, 2024). It originates in the districts of Hevié, Ouèdo, and Togba, flowing through the Godomey district in the commune of Abomey-Calavi, located in the southern Atlantic department of Benin, before discharging into Lake Nokoué. Along this river, numerous human activities take place. Figure 1 presents the geographic locations of the Sô and Djonou Rivers.

Hydrologically, the Atlantic Ocean, Lake Nokoué, the Djonou and Todouba rivers, and the surrounding temporary or permanent hydromorphic depressions represent significant water bodies that influence human activities within the commune of Abomey-Calavi. The main rivers feeding into Lake Nokoué include the Ouémé River, the Sô River, and the Djonou Lagoon. Lake Nokoué is connected to the Porto-Novo Lagoon to the east by the Totché Canal. The Todouba, Dati, and Ahouangan rivers are also tributaries of the Djonou Lagoon (ACDT, 2019).

Figure 1: Map of the Lake Nokoué-Sô River-Djonou River system.

2.2 Materials

A motorized boat is used for transportation along the two rivers. A GPS (Global Positioning System) is used for geographic coordinate acquisition. A WTW 340i multi-parameter analyzer (Conductimeter 340i) is employed to measure salinity, total dissolved solids (TDS), temperature, conductivity, and dissolved oxygen. A WTW 340i pH/Oximeter was used for pH measurements. A DR 5000 spectrophotometer is used for nutrient analysis. Suspended solids (SS) and turbidity were measured using a HACH DR 890 colorimeter.

2.3 sampling and data collection

Water samples were taken at the sites identified during the survey phase (inventory of anthropogenic pressures on the Sô and Djonou rivers) in order to :

- to have a good distribution of these points along the two rivers
- to take into account places where household refuse and other waste is dumped.

Fieldwork was carried out using a zodiac and drowning protection buoys. The water samples are taken at a depth of 50 cm from the surface of the water using a Van Dorn bottle to obtain sub-samples of 1.5 L. The water samples taken were automatically stored in coolers at 4°C and sent to the Applied Hydrology Laboratory for chemical analysis.

Figure 2 shows where the water samples were taken.

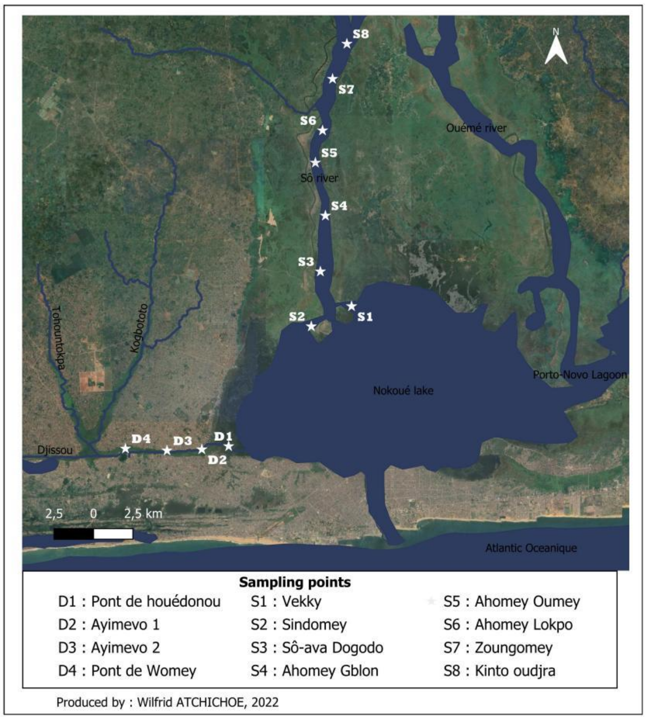

Figure 2: Map of the Lake Nokoué-Sô River-Djonou River system with water sampling points

2.4 Analysis methods

The analysis methods are referenced and standardised according to AFNOR or contained in Rodier and al, 2009 and referenced in table 1 below. The levels of nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+) and phosphates (PO_4^{3-}) are determined in the water samples using a DR 5000 Spectrophotometer.

Table 1: Analytical references

Chemical parameters analysed	Analytical references
Conductivity, Temperature, pH, salinity, dissolved oxygen, , Total Dissolved Solids (TDS)	Direct measurement by multi-parameter Ph/Oximeter WTW 340i
Suspended solids, turbidity	Colorimeter HACH DR/890, Method 8025
Nitrites	Diazotization method
Nitrates	Salicylate reagent method
Ammonium	Nessler reagent method
Total Phosphorus and Ortho-Phosphates	Acid ascorbic Method
Chlorophyl a	Lorenzen (1967)
Biochemical Oxygen demand after five days (BOD5)	Oxytop respirometric method in a thermostatcic chamber
Chemical Oxygen demand	AFNOR NF T90-101, colorimeter, potassium dichromate method
Fe, Cd, Pb, Mn	atomic absorption spectrometry (AAS)

- Statistical analyses were performed using RStudio software, which enabled the generation of descriptive statistics tables, box plots, variability curves for the parameters, correlation matrices, and Principal Component Analysis (PCA) graphs.

3. RESULTS AND DISCUSSION

3.1 RESULTS

Table 2 and 3 respectively present the descriptive statistics of the physico-chemical parameters of the Djonou and Sô rivers.

Table 2: Descriptive Statistics of the Physico-Chemical Parameters for the Djonou River

Parameters	**Mean**	**Standard Deviation**	**Coefficient of Variation (%)**	**Min**	**Max**	**Skewness**	**Kurtosis**
pH	6.99	0.41	5.855	6.20	7.93	0.28	-0.23
Conductivity (µS/cm)	217.67	102.75	47.2	23.00	500.00	0.76	0.48
Dissolved Oxygen (mg/L)	1.79	0.63	35.26	1.15	3.71	1.22	0.54
Salinity (PSU)	0.17	0.28	167.8	0.00	0.90	1.67	1.12
Temperature (°C)	28.97	1.35	4.66	25.70	30.90	-0.29	-1.14
Total Dissolved Solids (TDS, mg/L)	195.38	110.04	56.32	20.00	500.00	0.91	0.54
Suspended Solids (SS, mg/L)	25.65	13.86	54.06	1.00	48.00	-0.07	-0.89
Turbidity (NTU)	46.62	28.31	60.71	4.00	85.00	-0.04	-1.41
Nitrites (NO_2^-, mg/L)	0.88	0.87	99.17	0.02	2.46	0.85	-0.89
Nitrates (NO_3^-, mg/L)	0.34	0.72	211.76	0.00	3.09	2.38	5.02
Ammonium (NH_4^+, mg/L)	1.21	0.67	55.58	0.07	2.23	-0.42	-1.32
Phosphates (PO_4^{3-}, mg/L)	0.44	0.44	99.96	0.00	1.30	0.92	-0.58
Total Phosphorus (PT, mg/L)	0.69	0.62	89.88	0.00	2.14	0.67	-0.70
Chlorophyll a (Chla, mg/L)	0.33	0.65	197.23	0.00	4.00	4.11	19.30
Nitrogen Total (NT, mg/L)	3.23	2.47	76.64	0.18	8.25	0.63	-0.79
Iron (Fe, mg/L)	0.79	0.35	44.25	0.04	1.37	-0.51	-0.45
Manganese (Mn, mg/L)	0.67	0.43	63.51	0.10	1.30	0.11	-1.35
Cadmium (Cd, mg/L)	0.06	0.08	130.09	0.01	0.24	1.53	0.54
Lead (Pb, mg/L)	0.02	0.05	225.52	0.01	0.35	6.39	40.13
Chemical Oxygen Demand (COD, mg/L)	73.77	43.69	59.22	18.00	145.00	0.02	-1.61
Biochemical Oxygen Demand after Five Days (BOD_5, mg/L O_2)	28.90	34.28	118.64	2.00	116.00	1.52	1.05

Tableau 3 : Descriptive Statistics of the Physico-Chemical Parameters for the Sô River

Parameters	Mean	Standard Deviation	Coefficient of Variation (%)	Min	Max	Skewness	Kurtosis
pH	7.17	0.54	7.5	6.15	7.95	-0.29	-1.26
Conductivity (µS/cm)	2860.14	5193.17	181.57	17.50	27700.00	2.44	6.10
Dissolved Oxygen (mg/L)	4.44	2.91	65.57	1.00	12.50	0.46	-0.72
Salinity (PSU)	1.81	3.37	186.19	0.00	17.20	2.26	4.90
Temperature (°C)	30.20	1.38	4.58	27.80	33.20	-0.26	-0.80
Total Dissolved Solids (TDS, mg/L)	2859.57	5198.81	181.8	17.75	27700.00	2.44	6.08
Suspended Solids (SS, mg/L)	6.77	5.79	85.57	0.00	35.00	1.80	4.85
Turbidity (NTU)	10.80	6.43	59.55	0.00	37.00	0.66	1.32
Nitrites (NO_2^-, mg/L)	0.16	0.13	81.25	0.02	0.96	2.80	12.35
Nitrates (NO_3^-, mg/L)	0.64	1.24	193.75	0.00	6.39	2.72	7.84
Ammonium (NH_4^+, mg/L)	1.45	1.36	93.79	0.00	5.31	1.69	2.20
Phosphates (PO_4^{3-}, mg/L)	0.17	0.29	170.6	0.00	1.62	2.60	7.27
Total Phosphorus (PT, mg/L)	0.24	0.39	163.5	0.00	2.45	3.43	14.14
Chlorophyll a (Chla, mg/L)	0.29	0.49	166.5	0.00	3.36	3.96	18.40
Nitrogen Total (NT, mg/L)	3.19	2.73	85.5	0.03	10.89	0.88	-0.46
Iron (Fe, mg/L)	0.34	0.34	100.76	0.00	1.06	0.74	-0.90
Manganese (Mn, mg/L)	0.40	0.26	66.54	0.10	1.90	2.02	8.93
Cadmium (Cd, mg/L)	0.02	0.02	100	0.00	0.10	2.02	3.12
Lead (Pb, mg/L)	0.01	0.01	100	0.00	0.04	1.63	2.17
Chemical Oxygen Demand (COD, mg/L)	90.80	35.64	39.25	24.00	171.00	0.31	-0.12
Biochemical Oxygen Demand after Five Days (BOD_5, mg/L O_2)	24.02	13.89	57.82	4.00	69.00	1.26	1.36

Hydrogen potential (pH)

The pH values range from 6.20 (D3) to 7.93 (D1), with an average of 6.99 for the Djonou River, and from 6.15 (S5) to 7.95 (S5), with an average of 7.17 for the Sô River (Figure 3 and 4). The highest pH values are observed during the low-water periods, while the lowest values occur during the high-water periods. All of the pH values for both rivers are within the acceptable range of the

French NQE guidelines (6.5–8.5), except for the months of February, September, and October (Djonou) and February, June, and November (Sô), when values below 6.5 are recorded.

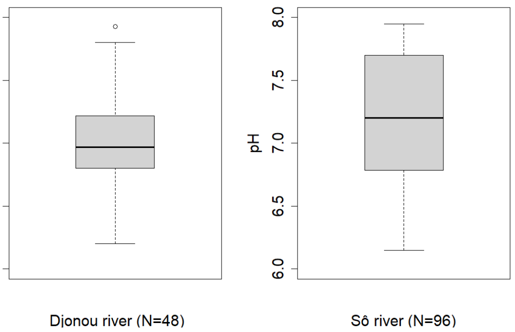

Figure 3: pH box plot

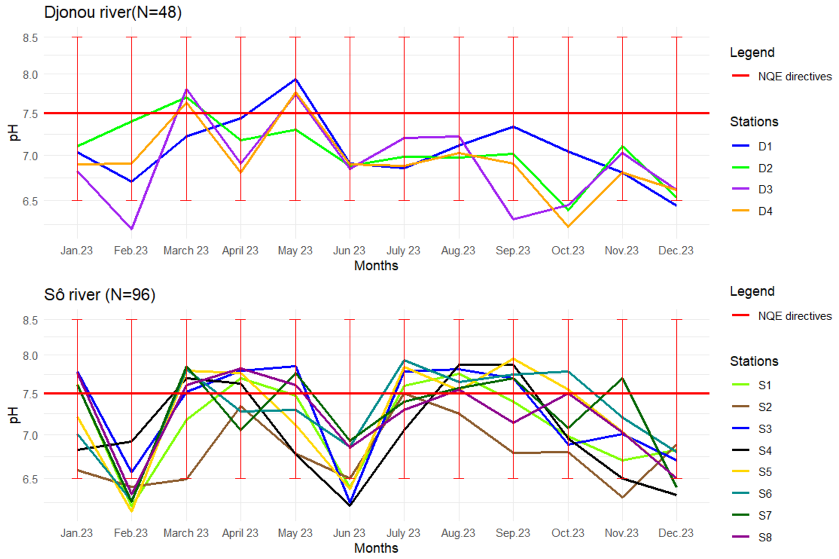

Figure 4: Changes in pH over time at stations on the Sô and Djonou rivers

Conductivity

The conductivity ranges from 23 µS/cm (D2) to 500 µS/cm (D1) with an average of 217.67 µS/cm for the Djonou River, and from 17.50 µS/cm (S2) to 27,700 µS/cm (S2) with an average of 2,860.14 µS/cm for the Sô River (Figure 5 and 6). The highest values are observed during the dry season (March to May and July to September) on the Sô River, and these values began to decrease following the first rains in June, with a significant drop during the high-water period in October. In contrast, the Djonou River shows the lowest conductivity values during the low-water period, while moderate to higher values are recorded during the high-water period (mid-June to mid-September). All the values obtained at the sites on the Djonou River comply with the French NQE guidelines (1000 µS/cm). However, the high values observed during the dry season on the Sô River (exc ce.

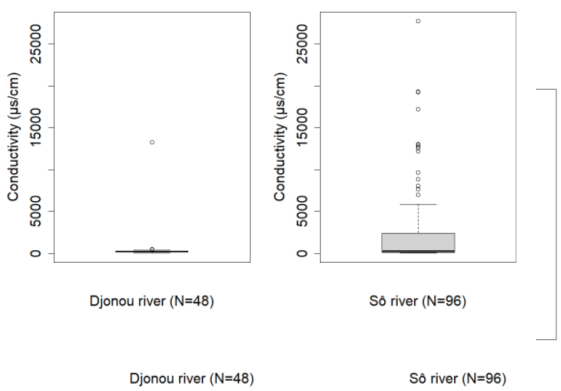

Figure 5: Conductivity box plot électrique

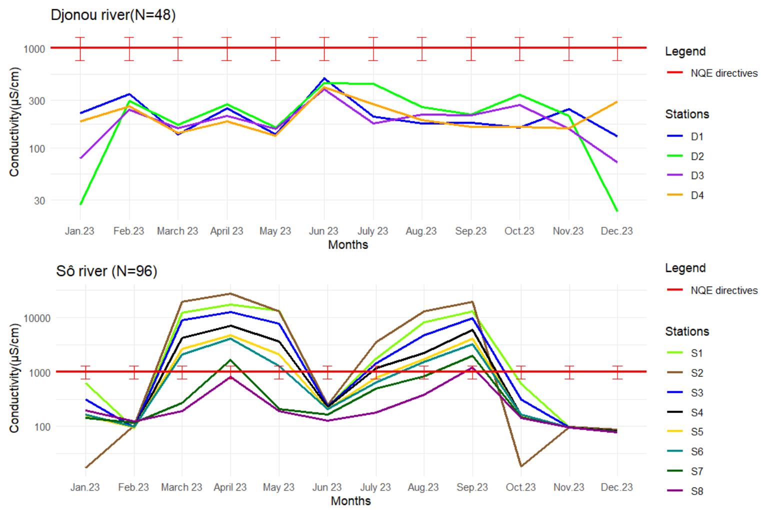

Figure 6: Changes in conductivity over time at stations on the Sô and Dionou rivers

Dissolved oxygen (DO)

Dissolved oxygen values range from 1.15 mg/L (D4) to 3.71 mg/L (D4), with an average of 1.79 mg/L for the Djonou River, and from 1 mg/L (S7 & S8) to 12.5 mg/L (S4), with an average of 4.44 mg/L for the Sô River (Figure 7 and 8). For both rivers, the highest concentrations of dissolved oxygen are observed during the dry season (mid-February to mid-May, mid-July to September), while the lowest concentrations occur during the rainy season (May to June, mid-September to October). For the Djonou River, all dissolved oxygen values at the various stations comply with the French NQE guidelines, which set the limit at 6 mg/L. For the Sô River, dissolved oxygen concentrations at the stations generally meet the NQE France guidelines, except for stations

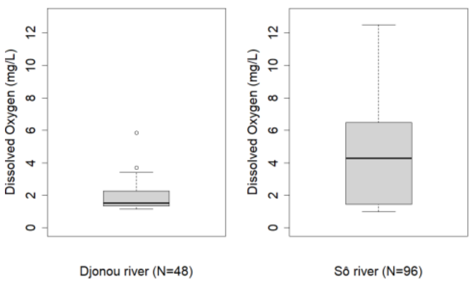

Figure 07: Dissolved oxygen box plot.

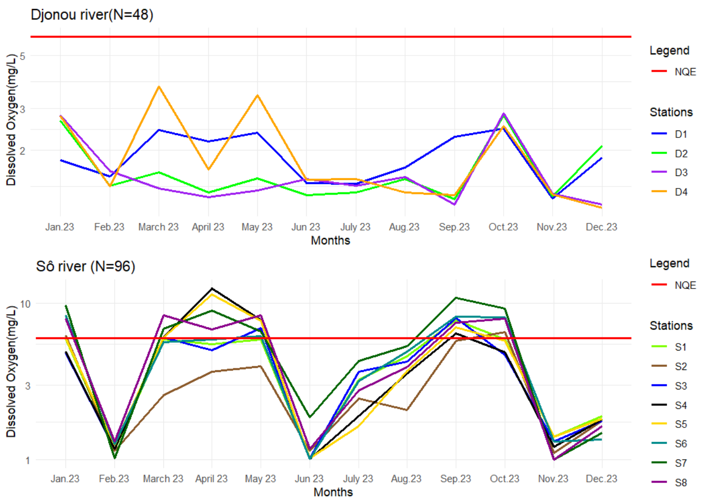

Figure 08: Trends in dissolved oxygen over time at stations on the Sô and Djonou rivers.

S6, S7, and S8, which present values exceeding 6 mg/L (NQE France guidelines) during the dry season.

Salinity

Salinity values range from 0 PSU (D1 to D4) to 0.9 PSU (D2) with an average of 0.17 PSU for the Djonou River, and from 0 PSU (S1 to S8) to 17.20 PSU (S2) with an average of 1.81 PSU for the Sô River (Figure 9 and 10). In the Sô River, significant salinity values are recorded during the dry season (February to May, mid-July to mid-September), and all of these values exceed 0.1 PSU (French NQE guideline). However, these values began to decrease at the onset of the rainy season, ultimately reaching zero during the high-water period. In contrast, for the Djonou River, high salinity concentrations are observed during the dry season (mid-July to mid-September and March), while the lowest values occur during the high-water period, with all values exceeding the NQE guideline of 0.1 PSU.

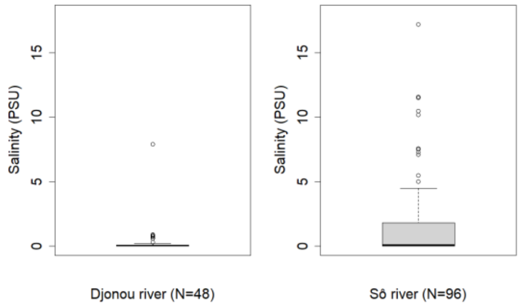

Figure 9: Salinity box plot

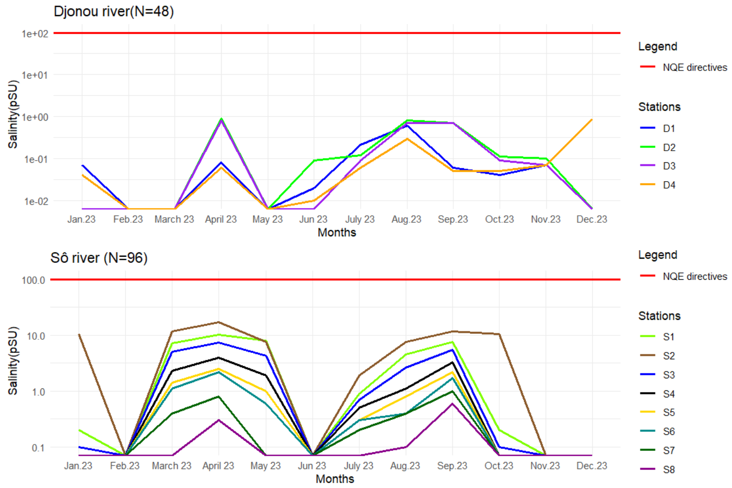

Figure 10: Changes in salinity over time at stations on the Sô and Djonou rivers

Température

Temperature values range from 25.7°C (D1) to 30.90°C (D2), with an average of 28.97°C for the Djonou River, and from 27.80°C (S1) to 33.20°C (S7), with an average of 30.2°C for the Sô River (figure 11 et 12). In both rivers, the highest temperatures are observed during the dry season, lasting until the first rains (October to May), while the lowest values are recorded during the high-water period (June to September). All temperature values recorded at the stations along both rivers exceed 25°C, in compliance with the French NQE guideline.

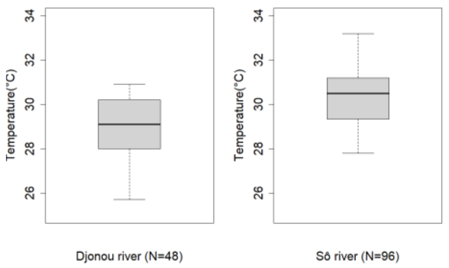

Figure 11: Temperature box plot

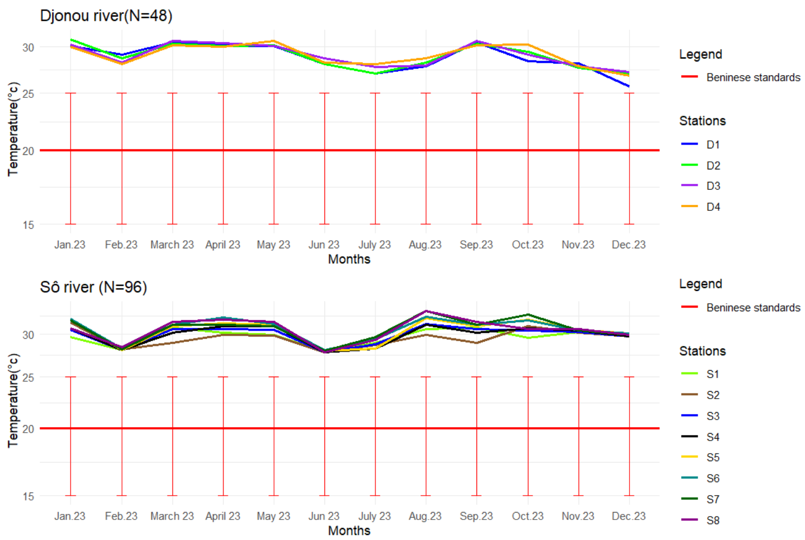

Figure 12: Temperature trends over time at stations on the Sô and Djonou rivers

TDS

TDS values range from 20 mg/L (D2) to 500 mg/L (D1), with an average of 195.38 mg/L for the Djonou River, and from 17.75 mg/L (S2) to 27,700 mg/L (S2), with an average of 2,859.57 mg/L for the Sô River (Figure 13 and 14). The highest values are observed during the dry season on the Sô River, and these values begin to decrease following the first rains in June, dropping significantly during the high-water period (September to October). In the case of the Djonou River, the lowest TDS values are recorded during the dry season, while more considerable values are observed during the rainy season (May-July). All values obtained at the Djonou sites comply with the French NQE guidelines (500–1200 mg/L). However, the high TDS values recorded at the Sô River exceed the upper limit set by the French NQE guidelines.

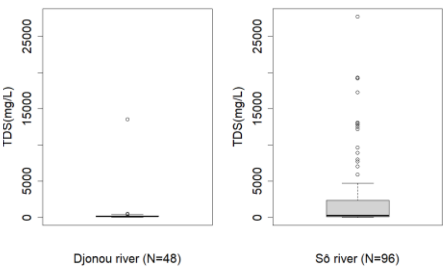

Figure 13: TDS box plot

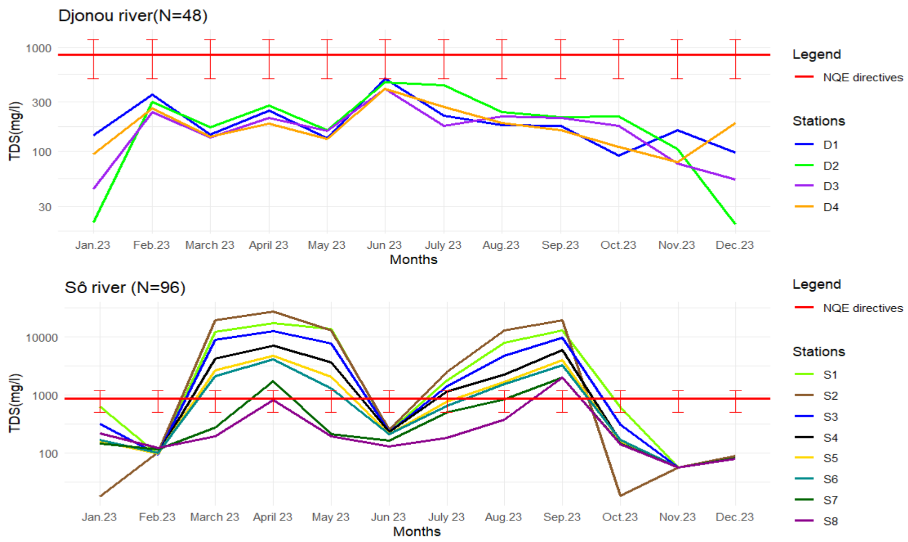

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Figure 14: Trends in TDS values over time at stations on the Sô and Djonou rivers

Nitrites

Nitrites vary from 0.02 mg/L (D1 and D2) to 2.46 mg/L (D2) with an average of 0.88 mg/L (Djonou river) and from 0.02 mg/L (S1) to 0.96 mg/L (S3) with an average of 0.16 mg/L (Sô river) (figure 15 and 16). In the Sô, nitrite values are relatively low in all seasons. However, a considerable value was obtained at station S3 in September. In addition, in the Djonou river, nitrite values are low at all stations, although considerable values are obtained in the dry season at stations D2 and D3.

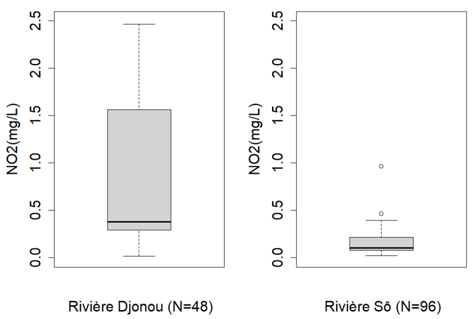


Figure 15: Nitrite box plot.

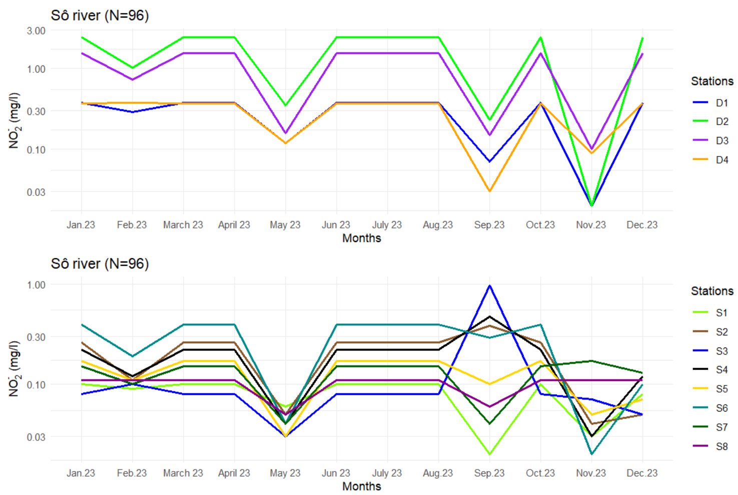


Figure 16: Nitrite values over time at stations on the Sô and Djonou rivers.

Nitrates

Nitrates vary from 0 mg/L (D1 to D4) to 3.09 mg/L (D4) with an average of 0.34 mg/L (Djonou river) and from 0 mg/L (S1 to S8) to 6.39 mg/L (S4) with an average of 0.64 mg/L (Sô river) (figure 17 and 18). For both rivers, significant values are observed in the rainy season and during high-water periods.

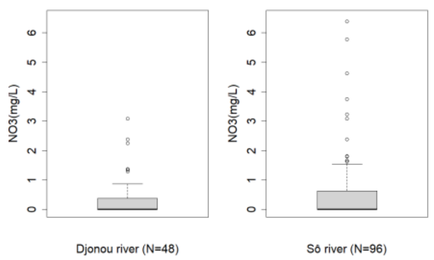


Figure 17: Nitrates box plot.

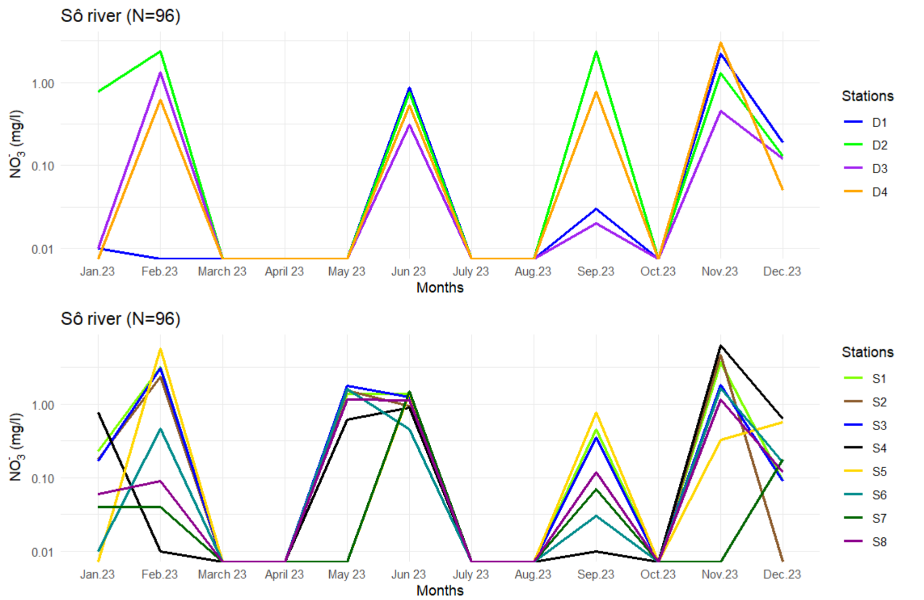


Figure 18: Changes over time in nitrate values at stations on the Sô and Djonou rivers.

Ammonium (NH_4^+)

Ammonium (NH4+) varies from 0.07 mg/L (D1) to 2.23 mg/L (D4) with an average of 1.21 mg/L (Djonou river) and from 0 mg/L (S7) to 5.31 mg/L (S2) with an average of 1.45 mg/L (Sô river) (figure 19 and 20). In the Sô river, high ammonium values were obtained at all stations during the dry season. These values far exceed the limit set by the French NQE guidelines (0.5 mg/L) and the low values are obtained in the rainy season. As for the Djonou river, the values are higher than the French NQE guidelines in all seasons except at the beginning of the rainy season (June) and during the flood period (September), when we notice a drop in these values.

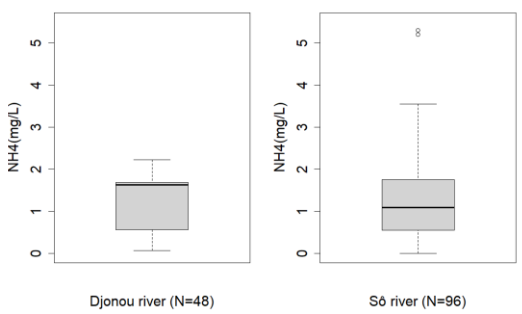


Figure 19: Ammonium box plot

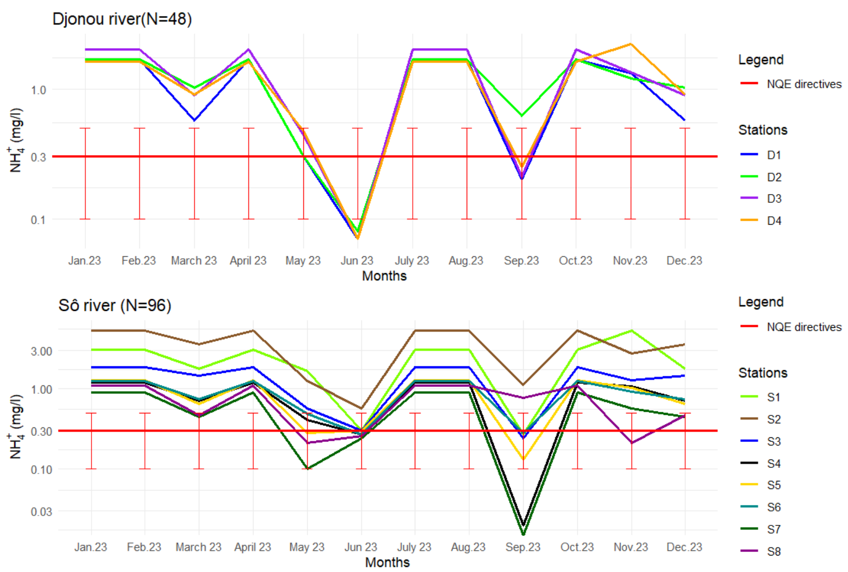


Figure 20: Changes in ammonium values over time at stations on the Sô and Djonou rivers

Total Phosphorus

Total phosphorus concentrations range from 0 mg/L (D3) to 2.14 mg/L (D1) with an average of 0.69 mg/L in the Djonou River, and from 0 mg/L (S1 to S8) to 2.45 mg/L (S2) with an average of 0.24 mg/L in the Sô River (figure 21 and 22). In the Sô River, low concentrations are observed across all seasons and stations, except at stations S8 (December) and S2 (November), where values exceed the Beninese standard limit of 2 mg/L. In the Djonou River, low phosphorus levels are consistently observed throughout the year at all stations, except at station D1, where a peak value exceeding the Beninese standard is observed in November.

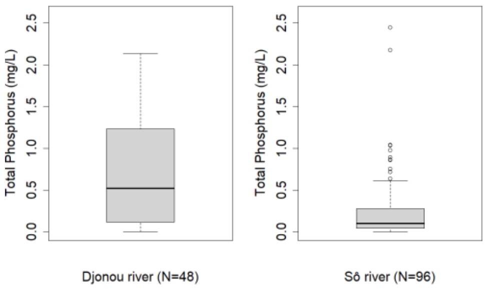


Figure 21: Total phosphorus box plot.

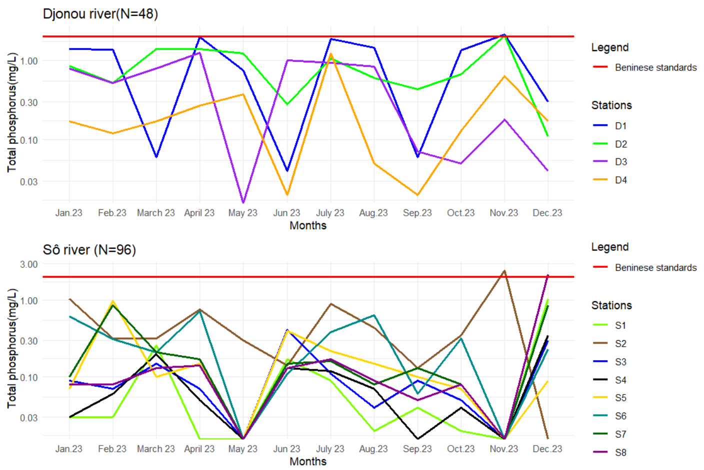


Figure 22: Trends in total phosphorus values over time at stations on the Sô and Djonou rivers

Chlorophyll-a

Chlorophyll-a concentrations range from 0 mg/L (D2 and D3) to 4.01 mg/L (D1) with an average of 0.33 mg/L in the Djonou River, and from 0 mg/L (S4 and S7) to 3.36 mg/L (S5) with an average of 0.29 mg/L in the Sô River (figure 23 and 24). In both rivers, chlorophyll-a levels are very low or undetectable across all stations during both the dry and rainy seasons, except between June and August. During this period, detectable levels of chlorophyll-a are observed, with notably higher concentrations in June at all stations.

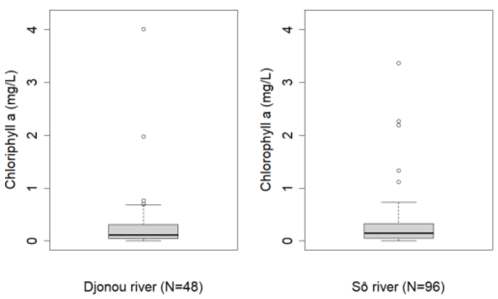


Figure 23: Chlorophyll a box plot.

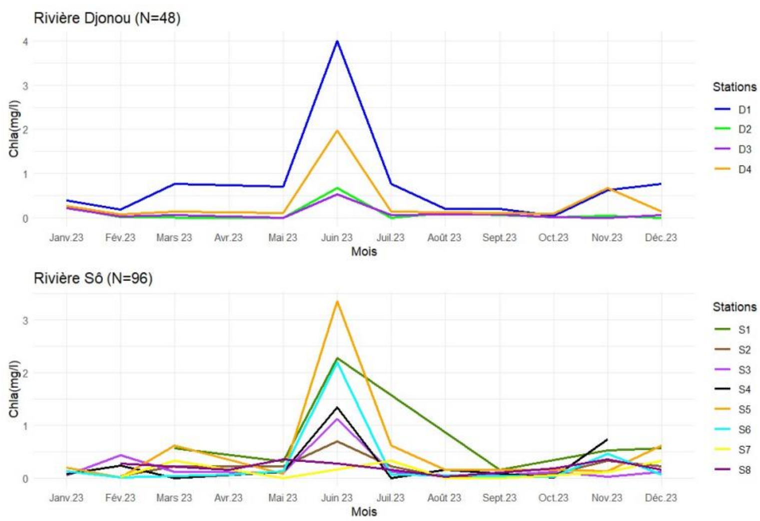


Figure 24: Chlorophyll a values over time at stations on the Sô and Djonou rivers.

Total Nitrogen

Total nitrogen concentrations range from 0.18 mg/L (D1) to 8.25 mg/L (D4) with an average of 3.22 mg/L in the Djonou River, and from 0.03 mg/L (S7) to 10.89 mg/L (S7) with an average of 3.19 mg/L in the Sô River (figure 25 and 26). Total nitrogen levels at all stations in both the Sô and Djonou Rivers across all seasons remain below the Beninese standard limit of 15 mg/L.

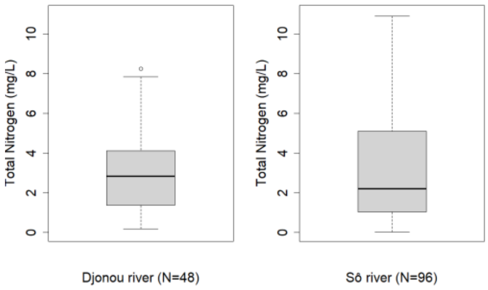


Figure 25: Total nitrogen box plot

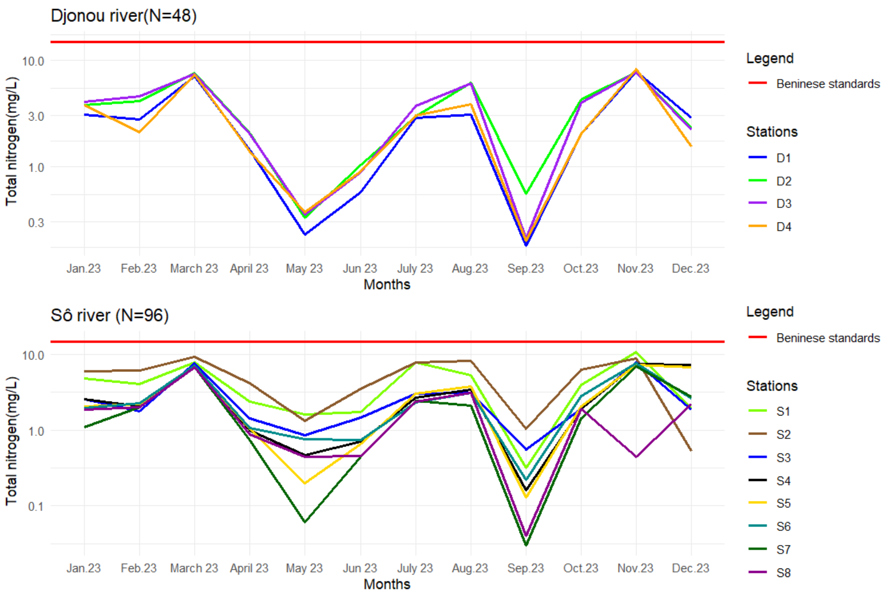


Figure 26: Changes over time in total nitrogen values at stations on the Sô and Djonou rivers

Cadmium (Cd)

Cadmium (Cd) concentrations range from 0.01 mg/L (D1) to 0.24 mg/L (D2) with an average of 0.06 mg/L in the Djonou River, and from 0 mg/L (S2, S4, and S7) to 0.10 mg/L (S7) with an average of 0.02 mg/L in the Sô River (Figure 27 and 28). In both rivers, cadmium concentrations remain relatively low across all stations during both the dry and rainy seasons. Notably, no station in either river exceeds the Beninese Lisec standard of 1 g/kg.

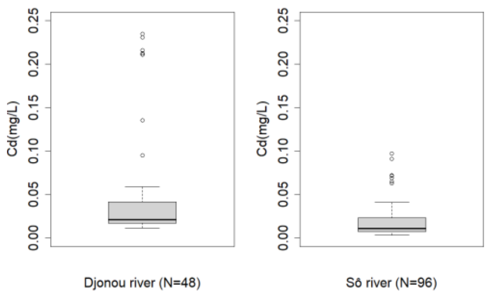


Figure 27: Cadmium box plot

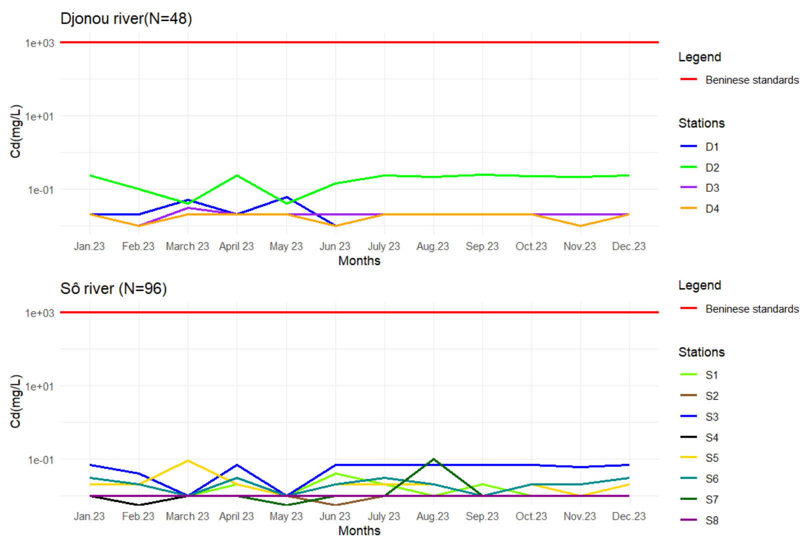


Figure 28: Cadmium values over time at stations on the Sô and Djonou rivers

Lead (Pb)

Lead (Pb) concentrations range from 0.01 mg/L (D1 to D4) to 0.35 mg/L (D1) with an average of 0.02 mg/L in the Djonou River, and from 0 mg/L (S2 to S8) to 0.04 mg/L (S3) with an average of 0.01 mg/L in the Sô River (Figure 29 and 30). In the Sô River, low lead levels are recorded across all stations and seasons, with minor increases at stations S7 (February) and S3 (during the rainy season). In the Djonou River, very low lead concentrations are observed at all stations from January to December, except at station D1, which shows a sharp increase in October. Notably, no station in either river exceeds the Beninese standard limit o[illegible]

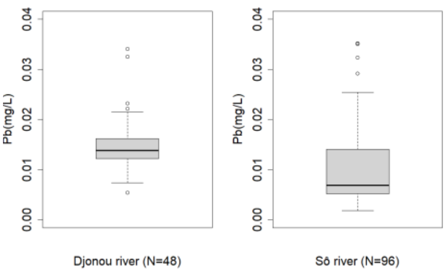


Figure 29: Box plot Lead

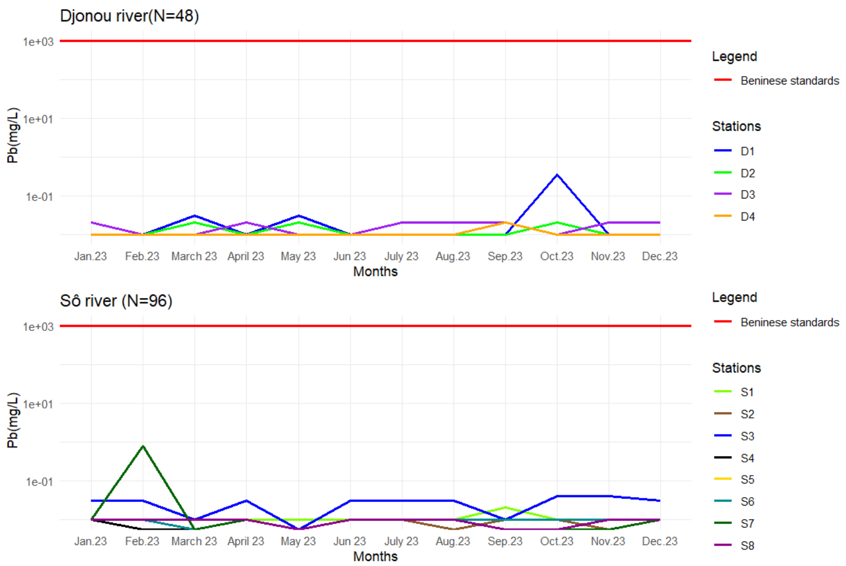


Figure 30: Lead values over time at stations on the Sô and Djonou rivers

BOD5

BOD5 varies from 2 mg/L O2 (D1) to 116 mg/L O2 (D2) with an average of 28.9 mg/L O2 (Djonou river) and from 4 mg/L O2 (S1) to 69 mg/L O2 (S6) with an average of 24.02 mg/L O2 (Sô river) (Figure 31 and 32). The high values in both rivers are obtained mainly during the dry season (March and May), and these high values far exceed the Benin standard (30 mg/L). During the rainy season, however, station D4 at Djonou and station S8 on the Sô both had values that were higher than the standard. The low values are obtained in the rainy season (June-September).

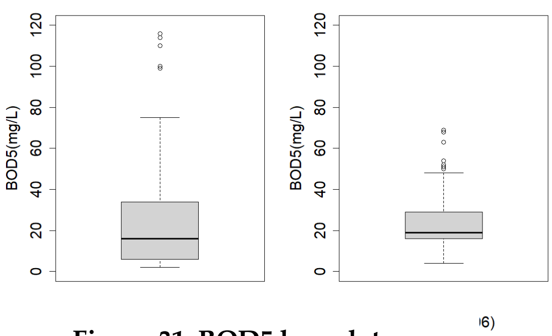


Figure 31: BOD5 box plot

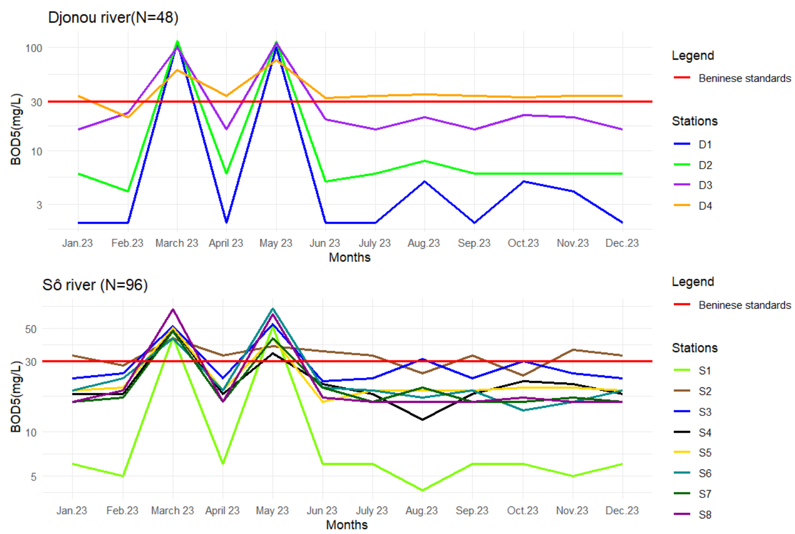


Figure 32: Trends in BOD5 values over time at stations on the Sô and Djonou rivers

Principal Component Analysis (PCA)

Tables 3 and 4 below respectively present the correlation between the physico-chemical parameters of the Sô and Djonou rivers

Table 4: Correlation matrix between physico-chemical parameters measured at stations on the river Sô

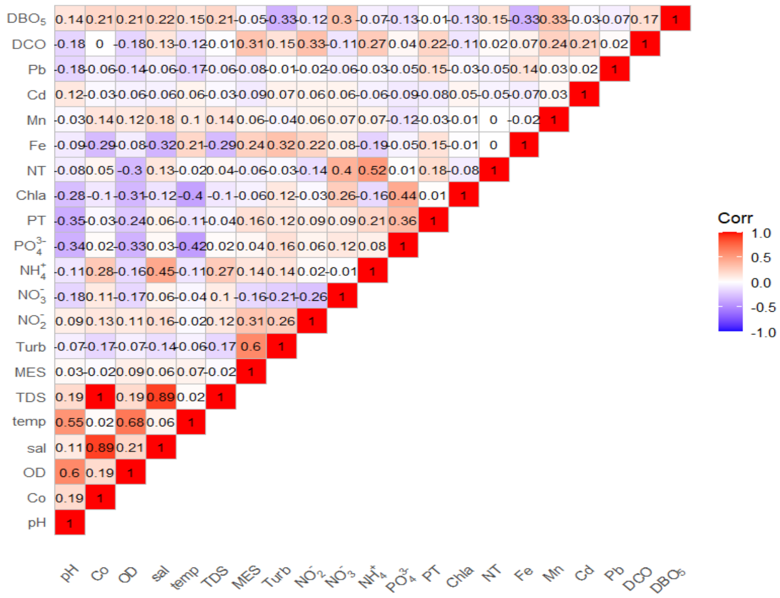
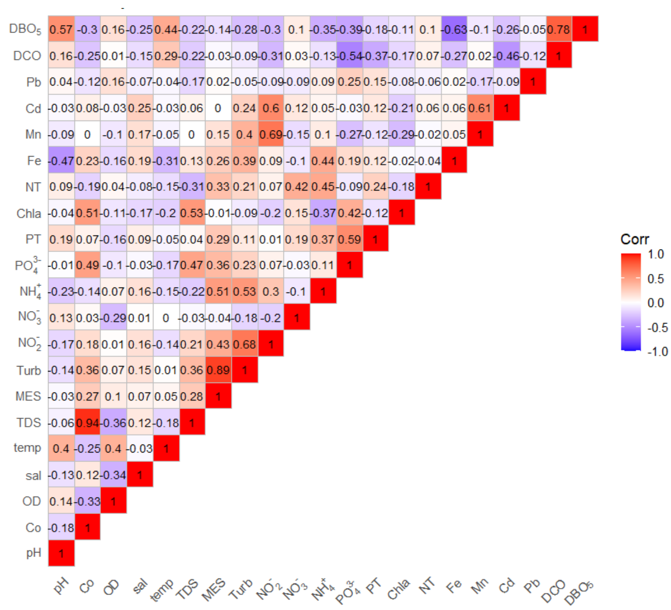


Table 5: Correlation matrix between physico-chemical parameters measured at stations on the Djonou



The results of the principal component analysis (PCA) (Figure 33) based on a correlation matrix between the annual means per season of the physico-chemical parameters of the Sô and Djonou rivers showed that 92.96% of the variance in the data is explained by the first 2 principal components. The first principal component of the PCA (Dim1) explains 67.6% of the variation in physico-chemical parameters, while the second principal component (Dim2) explains 25.3%.

In the Djonou river, the first principal component better explained the variation in parameters in the dry season, such as TSS, turbidity, NO_2^-, Mn, Cd and lead, while the second principal component better explained the variation in parameters in the rainy season, such as NT, Chlorophyll a, PO_4^{2-}, Total Phosphorus and Fe.

In the Sô river, the first principal component better explains the variation in dry season parameters such as BOD5, COD, dissolved oxygen and temperature, while the second principal component better explains the variation in wet season parameters such as TDS, conductivity, salinity, NH_4^+, NO_3^- and pH.

PCA was used to group the physico-chemical parameters by season and by river, as shown in Table 6.

Table 6: Grouping of parameters by season and by river.

Seasons	Main variables	Observation
Dry season (Djonou)	pH, Co, NO_2^-, Turbidity, COD, BOD_5	Increase in turbidity and dissolved organic matter (Co), probably due to low water dilution and evaporation. The pH was slightly higher, and chemical oxygen demand (COD) and BOD_5 also increased, indicating a greater organic load.
Rainy season (Djonou)	NO_3^-, NH_4+, SS, Fe, Pb	Increase in nitrates (NO_3^-), ammonium (NH_4^+), suspended solids (SS) and metals (Fe, Pb) due to soil run-off. Rain washes the soil and carries these elements into watercourses.
Rainy season (Sô)	NO_3^-, NH_4+, TDS, NT	Continued increase in NO_3^-, NH_4^+, total dissolved solids (TDS) and total nitrogen (TN), indicating strong mineralisation and the beginning of element concentration with the end of rainfall inputs
Dry season (Sô)	Salinity, DO, Mn, Cd	Increase in salinity (sal) and metals such as Mn and Cd is linked to intense evaporation and the concentration of elements in the remaining water. Probable decrease in dissolved oxygen (DO) due to poor circulation and reduced biological activity.

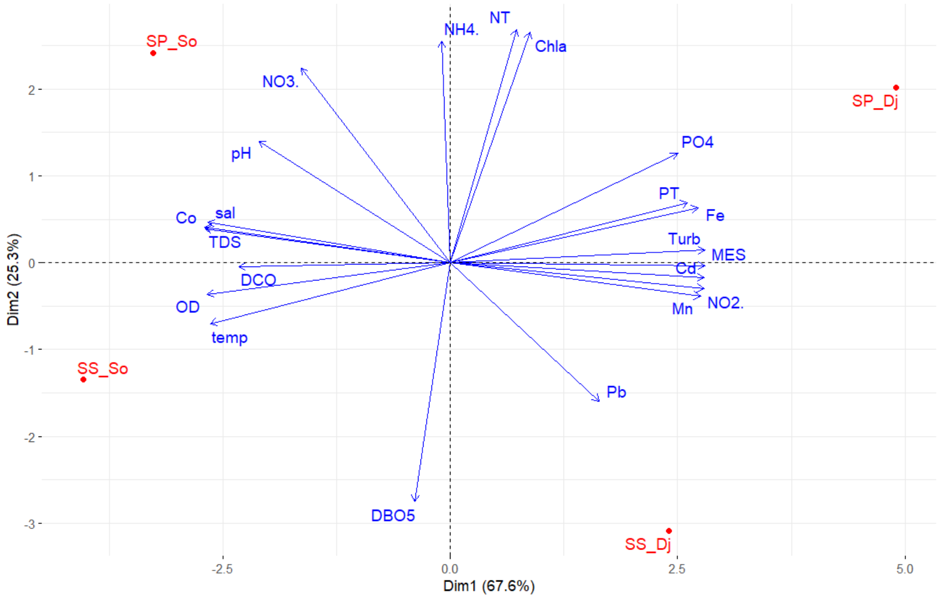


Figure 33: Principal component analysis of physico-chemical parameters by season (Sô and Djonou rivers).

Discussion

The pH is influenced by the environment through which the river flows, in particular its mineral composition, the type of soil and the rock itself (Korfali et al. 2011). In the present study, the high pH values observed at low water could be explained by discharges of domestic effluent of an alkaline nature (washing water) but also by the high photosynthetic activity of phytoplankton in these areas. These high values are also observed at stations where human activity is very high. However, the low values obtained in the rainy season could be explained by dilution of the river. In general, these values are mostly in the French NQE range (6.5-8.5) and are close to the results found by (Koudénoukpo et al .2017) on the River Sô.

Conductivity is defined as the property of a solution to conduct electric current. It can be used to quickly assess the degree of mineralisation of a water body, i.e. the quantity of dissolved ionised substances present. In the present study, the high values observed at low water levels in the Sô river are due to the high concentrations of dissolved ions in the water resulting from human activities, since a high electrical conductivity also indicates the degree of mineralisation of the water. This mineralisation is a function of the solubility of dissolved and dissociated compounds; this predicts a high ion content (Atibu et al. 2013). These high values in the Sô could also be explained by the fact that the tide influences the hydrological regime of this river during low-water periods with considerable inputs of dissolved salts, and are close to the values found by (Koudénoukpo et al.2017) on the Sô River. Djonou, on the other hand, has low mineralisation at low flow, which explains the low values observed in the dry season. The perimeter near the Djonou River is used for market gardening with the abusive use of fertiliser salt. During rainy periods, these products are washed into the river, leading to high mineralisation, which explains the high values observed in the rainy season in Djonou. These results are in contrast to (Ben et al . 2012), who state that low electrical conductivity in a watercourse is also synonymous with low mineralisation of the salts present in the environment. Thus, at the height of the rainy season, conductivity decreases as a result of the dilution of salts and ions due to rainfall.

Dissolved oxygen is one of the important parameters in the process of assessing water quality. Oxygen levels and saturation rates give an indication of the health of watercourses and make it possible, among other things, to assess the quality of fish habitats (Chouti et al. 2010). The high concentrations observed in the dry season in both rivers could be explained by a considerable reduction in oxidisable organic matter, which implies that the water is well oxygenated and that the environment is less polluted: such water is conducive to the development of aquatic fauna in general and zooplankton in particular (Buhungu et al. 2018). On the other hand, the low values observed at the beginning of the rainy season could be explained by the fact that the environment becomes loaded due to runoff and land leaching. As a result, the environment becomes loaded with organic matter and nutrients that are in the process of decomposing and require a lot of oxygen, leading to a drop in dissolved oxygen concentration due to the depletion of oxygen through the aerobic decomposition of organic waste by micro-organisms. A similar observation was made by (Mama et al. 2011) who showed that the lowest dissolved oxygen values are found at the beginning of the rainy season, which corresponds to the macrophyte decomposition period.

The high salinity values obtained at low water on the Sô can be explained by continental and marine interactions due to seasonal inflows of salt water from the Atlantic Ocean and the River Sô. The result obtained is in agreement with those of other bibliographies which stipulate that the spatial distribution of the salinity of the waters in Lake Nokoué according to their origin is under the control of the hydrodynamics generated by the winds of the lake (Boukari, 1998). At Djonou, high concentrations are observed in the rainy season due to excess fertilisers which run off directly into the river.

The temperature of surface water is used to assess its quality. It influences biological processes in aquatic systems (Kadlec and Reddy. 2001). Temperature is a key factor regulating the growth of zooplankton populations (Hong et al, 2003). The temperature values found in this study are close to the values found for waters in warm tropical regions (Buhungu et al. 2018). These values vary according to the season. The high values obtained in the dry season can be explained by the high insolation during this period.

TDS are equivalent to total mineralisation, i.e. the sum of anions and cations present in the water (Kambiré et al. 2014). Electrical conductivity and total dissolved solids (TDS) are strongly correlated in this study. This is consistent with the observation made by (Ewa et al. 2011) who recorded electrical conductivity strongly correlated with TDS in Omoku Creek River, Nigeria. Some authors claim that high electrical conductivity does not favour the development and proliferation of zooplankton (Monney et al. 2016).

Ammonia is often present in hydrosystems in the form of ammonium ion (NH_4^+). The results obtained in this study are similar to those found by (Koudénoukpo et al .2017) who state that the ammonium ion (NH_4^+in the River Sô has low values ranging from 0.71 to 2.34 mg/L. The high values exceeding the French NQE guidelines (0.5 mg/L) could be explained by the aerobic degradation of organic nitrogen (proteins, amino acids, urea), much of which comes from discharges of untreated domestic wastewater. $NH4^+$ itself is not harmful, but under certain conditions it can be transformed into ammonia (NH_3), a gas that is soluble in water and toxic to aquatic life (BE, 2012). (Hébert et Légaré . 2000) show that in a well-oxygenated environment, ammonium is rapidly used and its concentration is low. The levels in the two rivers (Sô and Djonou) are high and exceed the standard, which could pose a long-term threat to the aquatic ecosystem.

The high nitrate concentrations obtained at the end of the rainy season can be explained by leaching from cultivated areas (use of NPK fertiliser) drained by run-off water into the rivers, and also by poor waste management by the riverside population. These results are in phase with those found by (Mama et al. 2011) where it is observed that the evolution of nitrates on Lake Nokoué follows very markedly the concentration effect linked to evapotranspiration (high concentration in the dry season) and the dilution effect during high water (May-November).

Nitrite concentrations were low in both rivers. Although these concentrations are low, they can affect the development of aquatic species, as water containing nitrites, even in low doses, can be lethal for fish (Vissin et al. 2010). These values could be explained by the abundance of macrophytes, which would encourage fairly extensive nitrification of organic matter.

The Total Nitrogen values obtained are relatively low compared with the Benin standard, although significant values are obtained in the dry period (November and March). These high values may be associated with the decomposition of dead hyacinths and acadjas. This decomposition phase favours an increase in nitrogen concentration in the water column.

These results are in line with those found by (Koudenoukpo et al .2017) and (Mama et al .2011), who confirm that total nitrogen levels in the River Sô range from 3.91 to 5 mg/L, with an average of 4.56 mg/L.

Phosphates come from the decomposition of organic matter or leaching from agricultural land (Khalaf et al. 2007). The values obtained in the present study are close to those found by (Koudénoukpo et al .2017) and those obtained by (Buhungu et al.2018). These high values can be explained by the blatant lack of an adequate sanitation system, forcing the local population to discharge domestic wastewater into the rivers. It can also be explained by the erosion of arable land, where NPK fertiliser is used as a fertiliser, and by pig and cattle rearing, which leaves large quantities of faeces in the rivers when they roam. Assimilable by plants and photosynthetic organisms, They play a decisive role in the eutrophication of hydrosystems (BE, 2012). However, above a certain concentration and when conditions are favourable (low current, sufficient transparency, etc.), it can cause excessive growth of algae and aquatic plants (MEF, 2013).

The high Total Phosphorus values obtained at stations S2, S8 and D1 can be explained by excessive input of domestic wastewater because at D1 (Houédonou bridge), certain rituals are frequent and force users to bathe regularly with soap that is discharged directly into the Djonou River. The same cause can be attributed to points S8 and S2, which are areas of high human activity where toilets are almost non-existent, forcing the local population to pour their waste water into the river. These causes are compounded by the use of agricultural fertilisers in farming and market gardening.

Chlorophyll a is used to assess the productivity of a body of water. A low concentration of chlorophyll a can lead to a clean-water phase, which is an impoverished ecological state that occurs when there is a lack of biological activity in the water column (oligotrophy) caused by poor growth of algae and plants. Algae are an important source of food for primary consumers (benthic invertebrates and zooplankton), which has enormous consequences for the food chain. On the other hand, a high concentration of chlorophyll indicates the proliferation of algae and the proliferation of plants, which reduces the productivity of the ecosystem and disrupts the metabolism of many aquatic species.

Cadmium and lead are also present in trace amounts in both rivers. Their presence in both rivers may be of natural origin (soil leaching) or man-made (incineration of plastic waste and rechargeable batteries, phosphorus fertilisers, electronic products and paints). These metals are highly toxic, even in small doses, as they are one of the toxic contaminants of the aquatic environment and can therefore have serious repercussions on human health.

COD and BOD_5 are used to estimate the amount of pollution in a water sample. They are closely linked since the COD/BOD_5 ratio is an indicator of the biodegradability of the effluent. If this ratio is less than 2, the effluent is easily biodegradable. For this study, high BOD5 values were obtained in the dry season (a period of high concentration), which can be explained by the decomposition of macrophytes in rivers and the absence of dilution by freshwater (rainwater). This decomposition causes a significant consumption of dissolved oxygen, and will be accompanied by a deoxygenation of the environment, particularly at the water/sediment interface.

The PCA shows that the main sources of variation in the data are related to particle pollution and nitrate concentrations. TSS and turbidity are direct indicators of the impact of runoff and soil erosion, possibly linked to intense rainfall events or unsustainable agricultural practices. Nitrates reflect diffuse sources of pollution, often linked to human activities, such as the use of nitrogen fertilisers or the discharge of wastewater. This highlights the need to monitor and manage the use of agricultural land and sewage systems to avoid deterioration in water quality.

The physico-chemical characteristics of the water in the Sô and Djonou rivers in the dry season, which is rich in BOD_5, COD, TME (Pb, Mn, Cd), conductivity, NO_2^- and salinity, contrast with those of the water in the rainy season, which is rich in nutrients, particularly total phosphorus, PO_4, NT, NH_4^+ and NO_3^-. Some variables contribute significantly to the first two dimensions.

It should be noted that not all the watercourses tributary to Lake Nokoué are taken into account in this study. It would be scientifically useful to carry out a physico-chemical characterisation of the quality of the water in the Ouémé river (tributary of Lake Nokoué) so that the knowledge in terms of the contribution of pollutants from each tributary is exhaustive. Also, for subsequent studies, hydrological parameters such as flow rate must be associated with measurements of physico-chemical parameters in order to reason in terms of pollution flows from each tributary.

CONCLUSIONS

The study of the spatio-temporal variation of the Sô and Djonou rivers, tributaries of Lake Nokoué, made it possible to carry out a physico-chemical characterisation of these two tributaries. Out of 21 pollution indicator parameters studied on the two rivers, the following results were obtained:

- In the dry season, the Djonou river is rich in pH, Conductivity, NO_2^-, Turbidity, COD, BOD5
- In the dry season, the river Sô is rich in NO_3^-, NH_4^+, TDS, NT
- In the rainy season, the Djonou river is rich in NO_3^-, NH_4^+, Fe, Pb
- In the rainy season, the Sô river is rich in NO_3^-, NH_4^+,, TDS, NT

It is therefore clear that the Sô and Djonou rivers are polluted by TMEs and nitrogen and phosphorus nutrients, which will lead to eutrophication of the two tributaries and intoxication of their fish stocks, with all the attendant problems. There is an urgent need for continuous monitoring of these parameters in order to take appropriate mitigation measures (good waste management, promotion of organic farming, better supervision of livestock and ongoing awareness-raising among local residents) and thus avoid an environmental and health disaster in the long term.

ACKNOWLEDGEMENTS

The authors would like to thank the National Institute of Water (INE) at the University of Abomey-Calavi, through its African Centre of Excellence for Water and Sanitation (C2EA) and the Applied Hydrology Laboratory (LHA), for funding this study.

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