ESTIMATION OF POLLUTANT FLOWS IN THE SÔ AND DJONOU RIVERS TRIBUTARY TO LAKE NOKOUE IN WEST AFRICA.

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Abstract

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The aim of this study is to estimate the pollution flow of the tributaries (Sô and Djonou) of Lake Nokoué in Benin in West Africa. To achieve this, the pollutants influencing the two tributaries were quantified monthly for 12 months at the lake's entry points by molecular absorption spectrometry (chemical elements) and atomic absorption spectrometry (ETM). Daily flow records were obtained from Benin Institute for Fisheries and Oceanographic Research (IRHOB) and from water level sensors, in addition to long-term gauging data from the ADCP and the current meter. The flow was estimated using the method developed by the United States Environmental Protection Agency (1986). The result is that the Djonou river is subject to: a high organic load with average annual flows of ammonium, Biochemical Oxygen Demand and Chemical Oxygen Demand estimated at 462.47 Kg/d, 4225.73 Kg/d and 10595.79 Kg/d respectively; metallic pollution with an average annual flow of lead estimated at 18.20 Kg/d, and nitrogen pollution with average annual flows of nitrates and nitrites at 462.47 Kg/d and 276.55 Kg/d respectively. As for the river Sô, it is subject to nitrogen and metal pollution, with average annual flows of nitrates, ammonium, toatal nitrogen and cadmium estimated at 6029.10 kg/d, 7746.81 kg/d, 19764.43 kg/d and 328.47 kg/d respectively. Measures to mitigate these pollutants must therefore be taken in the short, medium and long term to save Lake Nokoué from environmental disaster.

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Introduction:

Lake Nokoué, bordering the city of Cotonou, the economic capital of Benin, with a population of 679,012 and an annual demographic growth rate of 018% (INSAE 2016), is a productive lake in West Africa with an annual yield of around one tonne per hectare, compared with 290 kg per hectare per year for all West African lagoons (Lalèyè et al. 2003). The lake is directly affected by domestic waste, with an annual volume of wastewater of 217 tonnes of BOD5 (Direction des pêches, 2004). Other sources of threat include industrial and agricultural effluents, pesticides and fishing, as well as strong saline intrusion (MAMA, 2010). Also, the impact of petroleum product traffic on Lake Nokoué and the Cotonou lagoon has resulted in very high levels of chemical pollution caused by the discharge of polycyclic aromatic hydrocarbons into the lake (Tossou, 2000). Metallic pollution (lead, copper and zinc) in the urban area of Lake Nokoué and the Cotonou channel has a negative impact on oysters (Senouvo, 2002). Excreta discharged into Lake Nokoué is the most important source of bacteriological pollution and deposits of acadja branches are the main source of organic pollution (Kouchade, 2002). The inventory of water bodies in southern Benin (Roche International, 2000) revealed the presence of chemical and microbiological pollutants and organic matter in Lake Nokoué.

The various tributaries of Lake Nokoué are the Ouémé, Sô and Djonou rivers. 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 which could lead to intoxication of people who consume fish resources; the latter are also exposed to the risk of asphyxiation (Sériki, 2018).

Lake Nokoué and its tributaries are subject to chemical, bacteriological and organic pollution, the main sources of which are human activities; then, on the Sô and Djonou rivers, 64% of households do not have a sanitation system and practise open-air defecation; 72% of households have poor waste management; 20% of households use NPK fertiliser in agriculture and market gardening in the immediate and immediate vicinity of the Sô and Djonou rivers; 69% of households water their livestock directly from the river; 3% of households trade in fuel, with the risk of oil products being spilled into the 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 the following diseases: malaria, chronic diarrhoea, skin infections (Atchichoe et al, 2024). In the dry season, the Djonou river is rich in Conductivity, NO_2^-, Turbidity, COD, BOD5 and the Sô river is rich in NO3-, NH4+, TDS, NT; in the rainy season, the Djonou river is rich in NO3-, NH_4^+, SS, Fe, Pb and the Sô river is rich in NO_3^-, NH_4^+, TDS, NT (Atchichoe et al, 2025).

Thus, several researches have been interested in the pollution of Lake Nokoué and its tributaries but very few have estimated the flows of the various pollutants which influence the quality of the tributaries of Lake Nokoué. This justifies the choice of our research subject entitled: estimation of pollutant flows in the Sô and Djonou rivers, tributaries of Lake Nokoué in West Africa.

Materials and Methods

Geographical location of the Sô and Djonou rivers

The Sô river runs mostly alongside the commune of Sô-Ava, which lies between latitudes 6°24' and 6°38' North and between longitudes 2°27' and 2°30' East (Benin Topo-foncier, 2006). It is located in the Atlantic and Littoral departments and occupies the lower valley of the River Ouémé (Bénin Topo-foncier, 2006). It is characterised by its wealth of bodies of water (65% of the territory), hence its name of lake commune, and covers an area of 218 km² with a population estimated in 2006 at ninety thousand seventy inhabitants (90, 0070) (Bénin Topo-foncier, 2006). It is bordered to the north by the communes of Zè and Adjohoun, to the south by the commune of Cotonou, to the east by the lakeside communes of Aguégués and Dangbo and to the west by the commune of Abomey-Calavi (Bénin Topo-foncier, 2006). It is subdivided into 42 villages spread over seven (07) arrondissements. These are the arrondissements of Sô-Ava, Veky, Houédo-Aguékon, Dékanmè, Ganvié I, Ganvié II and Ahomey-Lokpo (Bénin Topo-foncier, 2006). The River Sô rises in Lake Hlan and is linked to the River Ouémé by marigots (Figure 1). This river is one of the former branches of the Ouémé, which has since been detached, and which discharges its waters to the north-west of Lake Nokoué at the level of the lakeside town of Ganvié (Lalèyè, 1995). The river Sô is linked to the Ouémé by marigots. The highest flows are observed during floods. During these floods, the river floods the land and improves the yield of fish holes and 'acadjas'. The river Sô has several branches, all of which are navigable during the flood period. These are the Akassato, Gbéssou and Zoungomey branches. To the north, in the locality of Kinto, the river Sô forks into two branches forming a Y shape. The right-hand branch leads to Adjohoun; the left-hand branch leads to Kpomè in Sèhouè.

The Abomey-Calavi Commune's hydrographic network is essentially made up of two bodies of water, Lake Nokoué and the Djonou coastal lagoon. The commune is located in two watersheds. More than half of the commune (307 km^2) drains towards the Atlantic Ocean and the rest (224 km^2) drains towards Lake Nokoué. The commune also has a seafront juxtaposed with the coastal lagoon, marshes, streams and swamps.

From a hydrological point of view, the Atlantic Ocean, Lake Nokoué, the Djonou and Todouba lagoons and the depressions with temporary or permanent hydromorphy are the major bodies of water that influence human activities in Abomey-Calavi. The main tributaries of Lake Nokoué are the Ouémé and Sô rivers and the Djonou lagoon. The lake communicates with the Porto-Novo lagoon to the east via the Totché canal. The Todouba, Dati and Ahouangan rivers are in turn tributaries of the Djonou lagoon (ACDVT, 2019). The Djonou river lies between 6°22'31'"North and 2°19'40"' East. It rises in the arrondissements of Hevié, Ouédo and Togba and flows along the arrondissement of Godomey in the commune of Abomey Calavi in the Atlantic department of southern Benin, before flowing into Lake Nokoué. Many activities take place along this river. Figure 1 shows the geographical location of the Sô Rivers.

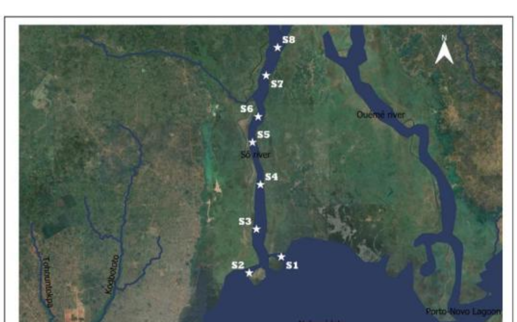
Figure 1: Map of the Lake Nokoué-Sô River-Djonou River system

Materials

A motorised boat was used to travel on the two rivers, and a GPS (Global Positioning System) was used to take geographical coordinates. A DR 5000 spectrophotometer to measure nutrients.

Water sampling and data collection

- Water samples were taken monthly at the entry points of each tributary into the lake from January 2023 to December 2023. Field work was carried out using a zodiac and drowning protection buoys. Water samples were taken from the water column 50 cm from the water surface using a Van Dorn bottle to obtain 1.5 L sub-samples. The water samples taken were automatically stored in coolers at 4°C and sent to the Applied Hydrology Laboratory for chemical analysis. Figure 2 below shows a sampling map with the entry points considered for the Sô (S3) and Djonou (D1) rivers for flow estimation.



- For daily flow data at the lake entry points, the daily flow records obtained from the Institut de Recherches Halieutiques et Océanographiques du Bénin for the year 2023 were used in conjunction with flow measurements at the ADCP (Sô) and the current meter (Djonou).

Method

- **Analysis method**

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

.**<u>Tableau 1</u>** : Analytical references

Chemical parameters	Analytical references
Nitrites	diazotization method
Nitrates	salicylate reagent method
Ammonium	Nessler reagent 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

- Gauging method

Flow measurement at the ADCP: Flow was determined at the level of the river Sô (S3) using a Doppler-effect device from RD Instruments. The device is fixed to a board attached to the boat and immersed in the water. It is connected to a computer running Win River Application software, which calculates the flow by integrating the velocity field in the section**.**

Flow measurement using a current meter: Flow measurements at station D1 on the Djonou river were carried out using a current meter (gauging in boots because the river is shallow at station D1). The procedure consisted of entering the watercourse with the reel pole and the meter. The section is marked out by a double decametre stretched perpendicular to the general flow. The pole is placed vertically at the height of the decameter, which makes it possible to locate the abscissa of the vertical. The pole is held so that the reel is pointing in the direction of the current. Gauging is then carried out point by point or by integration.

- Flux estimation method

- The flux estimation method developed by the United States Environmental Protection Agency (1986) and used by Chapra (1997) and Diallo (2019).

The mass flow of the parameters (expressed in g/s or kg/d) is calculated using the formula :

$$Flux = C \times Q$$

where C is the measured concentration (in mg/L) and Q is the mean monthly flow rate in m3/s. This method is in line with recognised practice in water quality and pollutant transport studies, and is commonly used in scientific work when concentrations are measured on a spot basis and flows vary daily. It allows daily variations to be smoothed out while maintaining a realistic estimate of the loads transported.

$$Flux_{estimated} = C_{sample} \times Q_{average\ mont\ hly}$$

he actual flow of a pollutant at a given station, over a period, is ideally given by:

$$Flux_{real} = \frac{1}{T}\int_0^T C(t) \times Q(t)dt$$

But in reality: We do not have C(t) (continuous concentration), We have Q(t) (daily flow rate), but only a few punctual values of C (often one measurement per month or per fortnight).

So we approximate this integral by a discrete value:

$$Flux_{estimate\ d} = C(s) \times \overline{Q_{mont\ h}}$$

Where: C(s) is the concentration measured at a date s, $\overline{Q_{mont\ h}}$ is the average flow rate over the month.

The theoretical error ε can be described qualitatively as :

$$\varepsilon = \left|\frac{Flux_{estimated} - Flux_{real}}{Flux_{real}}\right|$$

$$\varepsilon = \left|\frac{C(s) \cdot \bar{Q} - \frac{1}{T}\int_0^T C(t) \cdot Q(t)dt}{\frac{1}{T}\int_0^T C(t) \cdot Q(t)dt}\right| \times 100$$

But as C(t) is not known, this error is not directly measurable.

Results and Discussion

- Chemical data

The study is based on the major chemical parameters that influence each tributary in both the dry and wet seasons.

Tableau 2: Monthly log of values for chemical parameters influencing the Djonou River

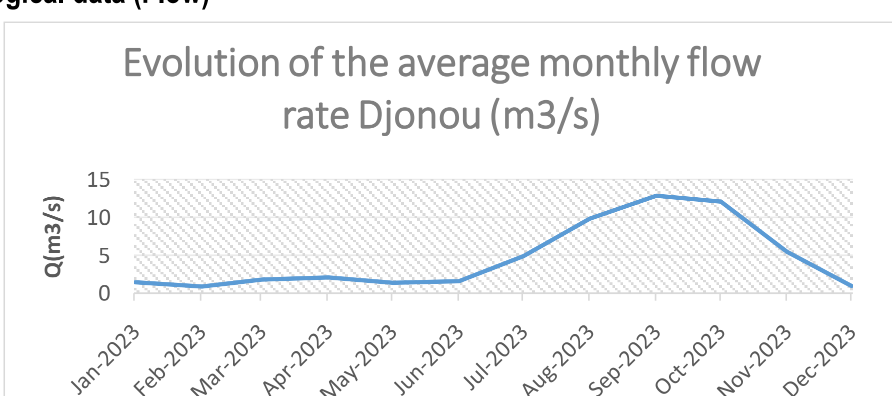
	Djonou River						
	NO_3^- (mg/l)	NH_4^+(mg/l)	NO_2^- (mg/l)	Fe (mg/l)	Pb (mg/l)	COD (mg/l)	BOD5 (mg/l)
Jan-2023	0,101	0,29	0,11	0,2	0,0325	125	100
Feb-2023	0,018	0,57148	0,29	0,075	0,0341	142	114
Mar-2023	0,027	0,202	0,066	0,81	0,0131	20	42
April-2023	1,027	1,69	1,38	0,94	0,0143	20	2
May-2023	0,985	3,69	0,98	0,89	0,0101	30	5
Jun-2023	3,71	1,93	1,38	0,94	0,0143	20	2
Jul-2023	0,870	0,074	0,78	0,65	0,013	18	2
August-2023	0,559	1,69	0,88	0,62	0,0105	19	2
Sep- 2023	0,58	0,57	0,80	1,05	0,0143	20	2

Oct-2023	2,24	1,32	0,51	1,02	0,0132	28	4
Nov-2023	1,85	1,69	0,38	0,94	0,3543	25	25
Dec-2023	0,176	1,69	0,38	1,11	0,0143	20	22

Tableau 3 : Monthly log of values for chemical parameters influencing the river Sô

Sô River					
	NO_3^- (mg/l)	NH_4^+(mg/l)	NT (mg/l)	Mn (mg/l)	Cd (mg/l)
Jan-2023	1,080	0,56	0,85	0,6	0,0084
Feb-2023	1,079	1,45	7,65	0,6	0,0072
Mar-2023	0,34	0,23	0,55	0,8	0,0651
April-2023	1,34	2,83	1,44	0,5	0,0721
May-2023	1,80	2,83	3,15	0,3	0,0653
Jun-2023	1,25	2,83	3,02	0,5	0,0721
Jul-2023	1,264	0,29	1,45	0,6	0,0718
August-2023	0,89	1,83	1,781	0,2	0,0411
Sep- 2023	0,98	1,45	1,89	0,5	0,0721
Oct-2023	1,81	1,27	7,93	0,3	0,0628
Nov-2023	0,12	1,83	1,902	0,3	0,0689
Dec-2023	0,087	1,83	2,593	0,5	0,0721

- **Hydrological data (Flow)**



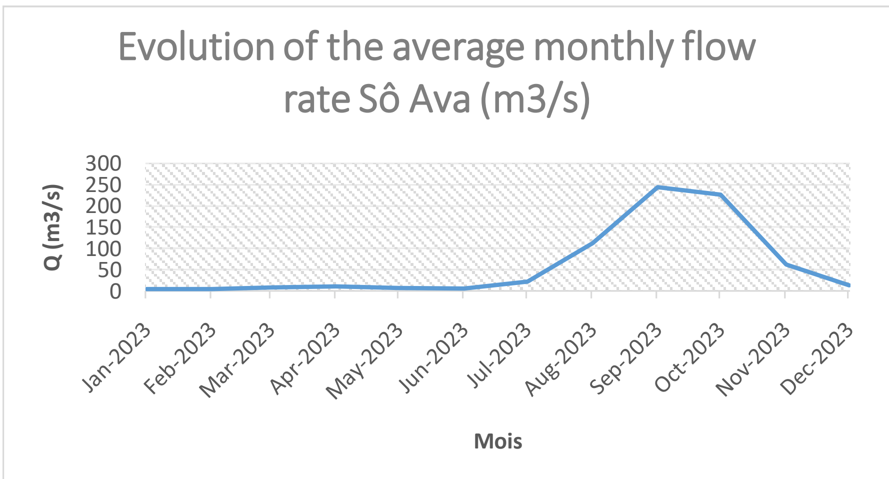


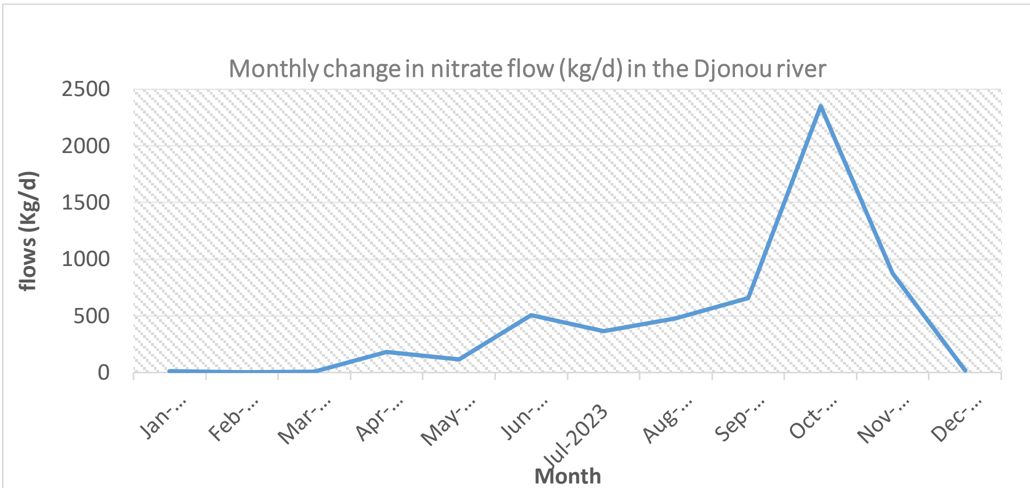
Tableau 4 : Mean annual flow of the Sô and Djonou rivers by season

Tributaries	station	season	Average annual flow
Sô River	S3 (Sô-Ava Degodo)	Dry	15,43 m^3/S
		High water	194,71 m^3/S
Djonou River	D1 (Pont de Houédonou	Dry	2,24 m^3/S
		High water	11,61 m^3/S

- Estimation of average flows of chemical parameters (NO_3^-, NH_4^+, Fe, Pb , NO_2^-, COD, BOD5) on the river Djonou

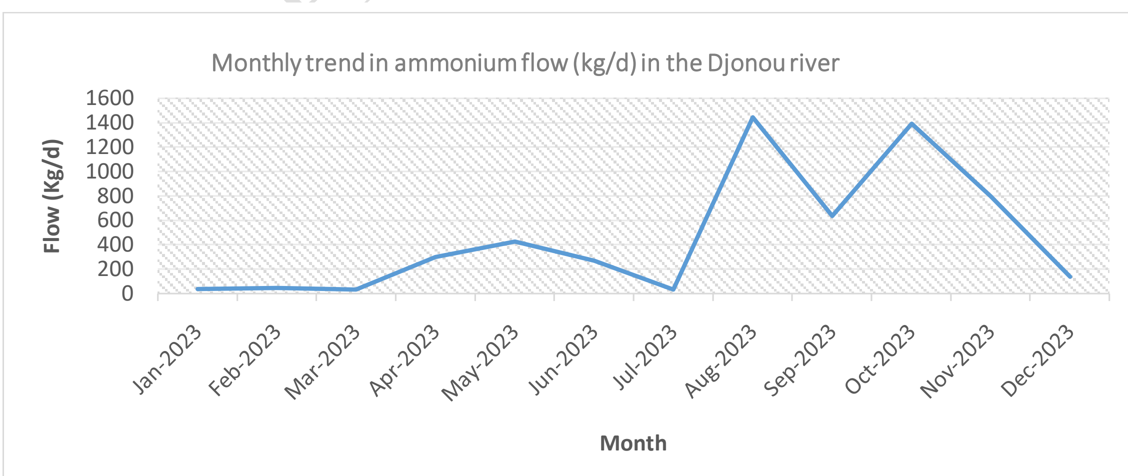
Average nitrate flows

At Djonou, nitrate flows vary from 1.35 kg/d (February) to 2,350.78 kg/d (September), with an average annual flow of 462.47 kg/d. In the dry season, the average flow of nitrate into the lake is 229.93 kg/d, and in the high-water period, it is estimated at 1160.09 kg/d.



Average ammonium flow

Ammonium flow varies from 30.82 kg/d (March) to 1441.51 kg/d (August) on the Djonou river, with an average annual flow of 460.44 kg/d. In dry periods, the average flow is estimated at 228.61 kg/d, and in periods of high water, it is 1155.91 kg/d.



Average nitrite flow

At Djonou, nitrite flow varies from 10.07 kg/d (March) to 899.29 kg/d (September), with an estimated average annual flow of 276.55 kg/d. The average nitrite flow during the dry season is 30.12 kg/d, rising to 730.04 kg/d during high-water periods..

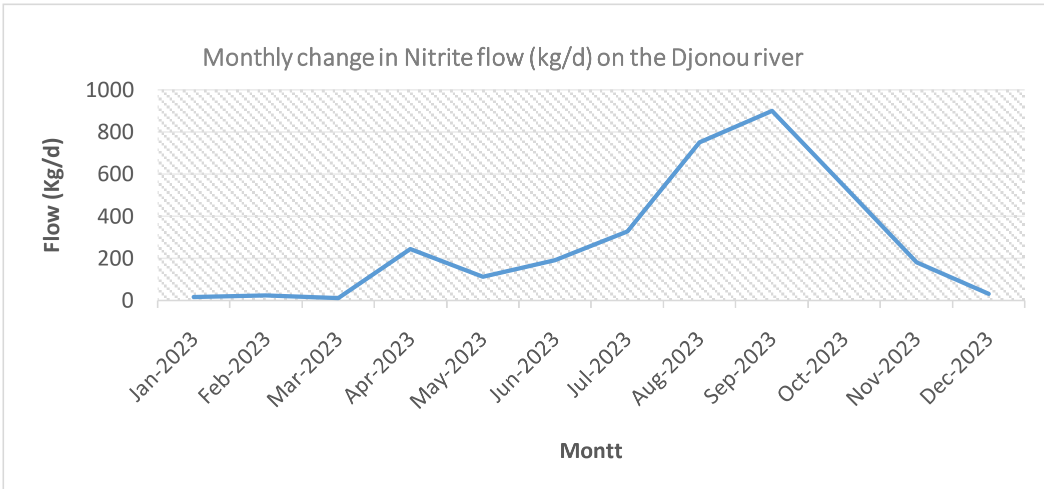


Figure: 7 Monthly change in Nitrite flow (kg/d) on the Djonou river

Average iron flow

The monthly iron flow varies from 5.62 kg/d (March) to 1167.26 kg/d (September) on the Djonou river, with an annual average of 342.88 kg/d. The average iron flow in the dry season is 150.24 kg/d, rising to 920.82 kg/d at high water.

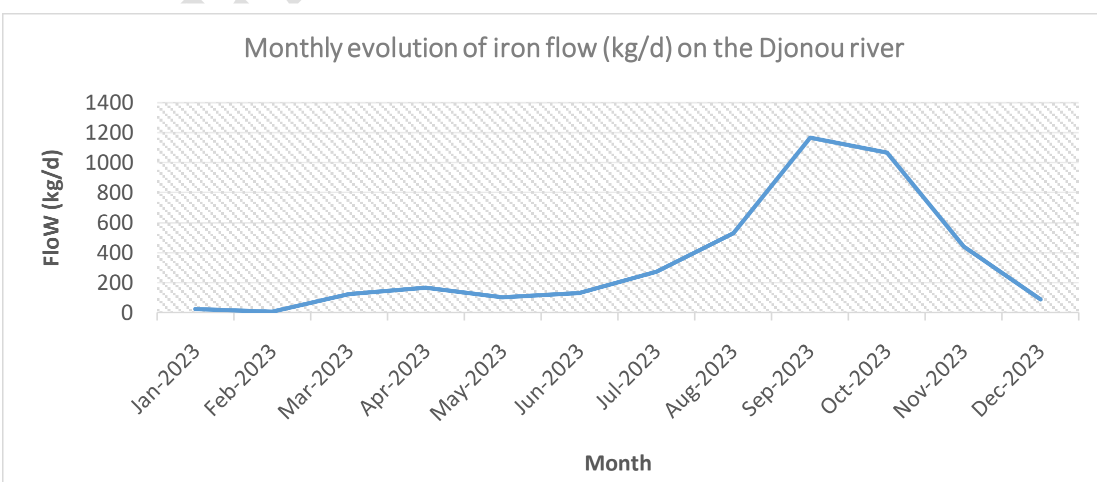
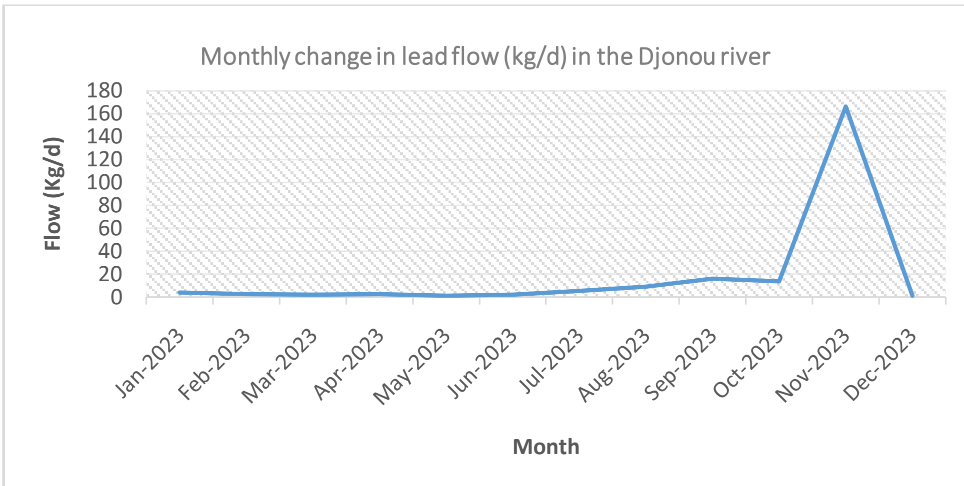


Figure 8: Monthly evolution of iron flow (kg/d) on the Djonou river

Average flow of lead

The monthly flow of lead varies from 1.13 kg/d (December) to 166.30 kg/d (November), with an estimated average annual flow of 18.80 kg/d. The average flow during the dry period is 20.78 kg/d and 12.88 kg/d during the high-water period.



Average flow of COD

On the Djonou River, the flow of COD varies from 1581.69 kg/d (December) to 29303.53 kg/d (October), with an estimated average annual flow of 10595.79 kg/d. In the dry and high-water periods, the average flow is 6604.5 kg/d and 22569.68 kg/d respectively.

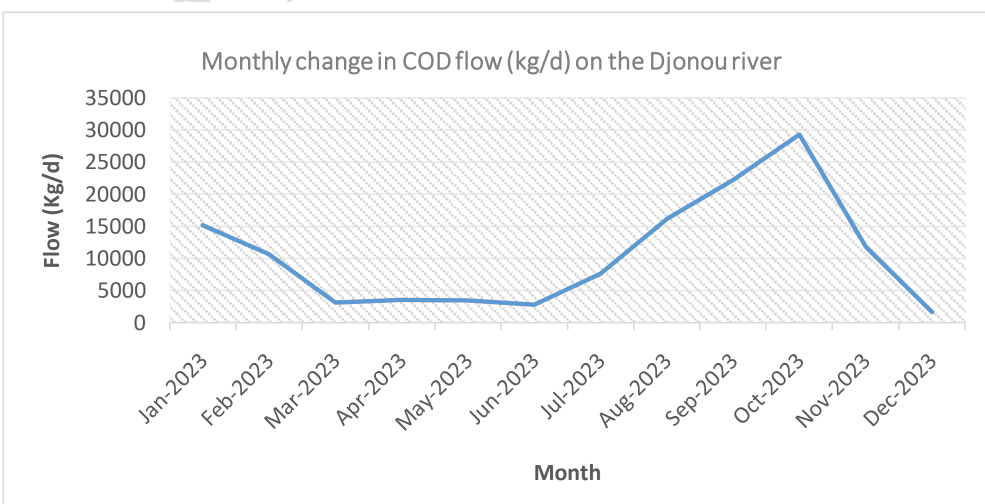


Figure 10: Monthly change in COD flow (kg/d) on the Djonou river

BOD5 flow

The monthly variation in BOD5 flow is from 273.54 kg/d (June) to 12120.48 kg/d (January) with an average annual flow of 4225.73 kg/d. The average flow in dry periods is 4,732.99 kg/d and 2,703.96 kg/d in periods of high water.

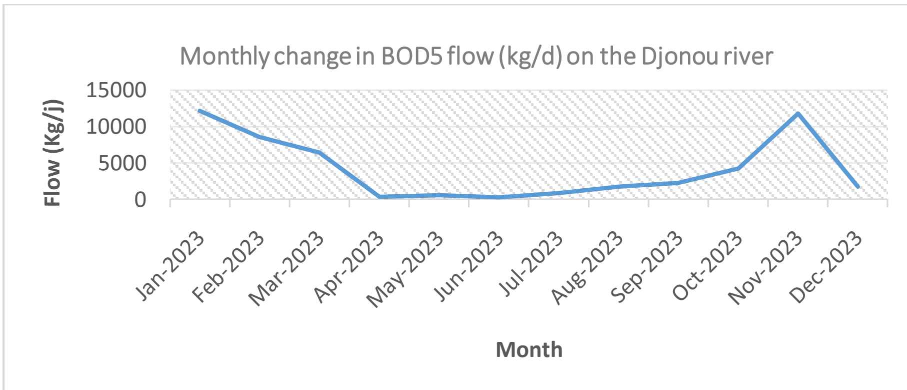


Tableau 5 : Estimation of average seasonal and annual flows at the Houédonou bridge (D1) on the Djonou river

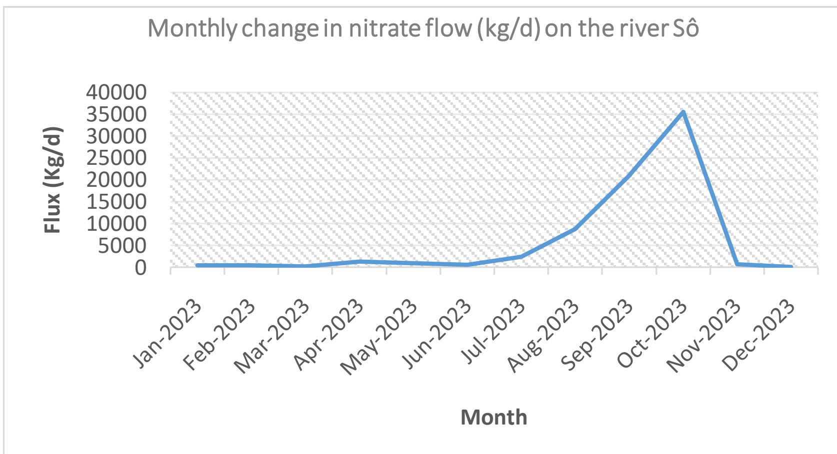
Djonou River					
	Min	Max	Average dry season flow	Average high water flow	Average annual flow
NO_3^- Flux(Kg/d)	1,35	2350,78	229,93	1160,09	462,47
NH_4^+- Flux (Kg/d)	30,82	1441,51	228,61	1155,91	460,44
NO_2^- - Flux (Kg/d)	10,07	899,29	30,12	730,04	276,55
Fe -Flux - (Kg/d)	5,62	1167,26	150,24	920,82	342,88

Pb- Flux (Kg/d)	1,13	166,30	20,78	12,88	18,80
COD-Flux(Kg/d)	1581,69	29303,53	6604,50	22569,68	10595,79
BOD5-Flux (Kg/d)	273,54	12120,48	4732,99	2703,96	4225,73

- Estimation of average parameter flows (NO_3^-, NH_4^+, NT, Mn, Cd) **on the river Sô**

average nitrate flow

Nitrate flows vary from 103.76 kg/d (December) to 35475.01 kg/d (October) on the river Sô, with an average of 6029.10 kg/d. The average flow in the dry and high-water periods is estimated at 802.96 kg/d and 21707.50 kg/d respectively.



Ammonium flows

Ammonium flows vary from 159.68 kg/d (March) to 30828.02 kg/d (September) at the Sô-Ava station, with an average annual flow of 7746.81 kg/d. During the dry period, an average flow of 2146.81 kg/d of ammonium passed through this station compared with an average flow of 24359.31 kg/d during the high water period towards Lake Nokoué**.**

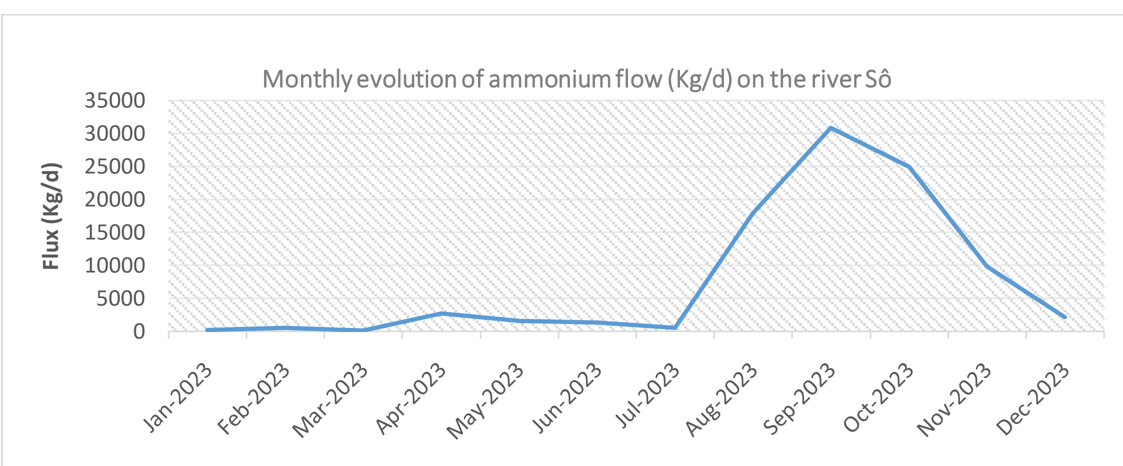
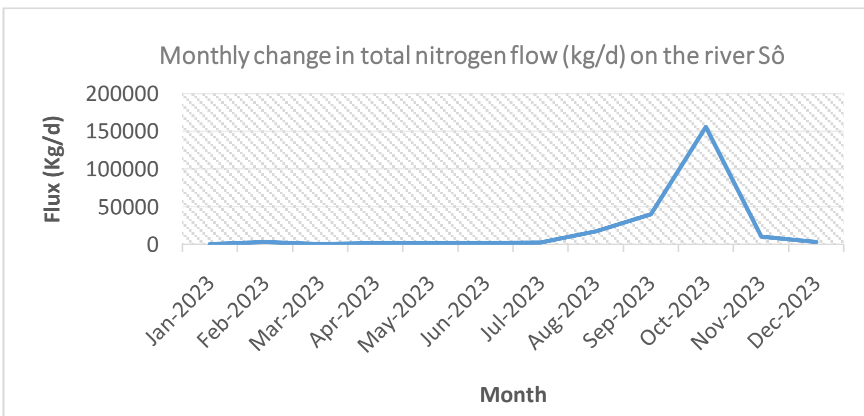


Figure 13: Monthly evolution of ammonium flow (Kg/d) on the river Sô

Total nitrogen flow

On the river Sô (Sô-ava), the estimated total nitrogen flow varies from 352.29 kg/d (January) to 155303.90 kg/d (October) with an annual average of 19764.49 kg/d. During the dry season, the average flow was 2719.90 kg/d, compared with 70898.03 kg/d at high water.



Manganese flow

The average annual manganese flow at Sô-ava is estimated at 1972.72 kg/d, varying from 169.09 kg/d (May) to 10560.52 kg/d (September). The average flow of Manganese in the dry period is estimated at 587.11 kg/d compared with 6129.55 kg/d in the high water period (August to October).

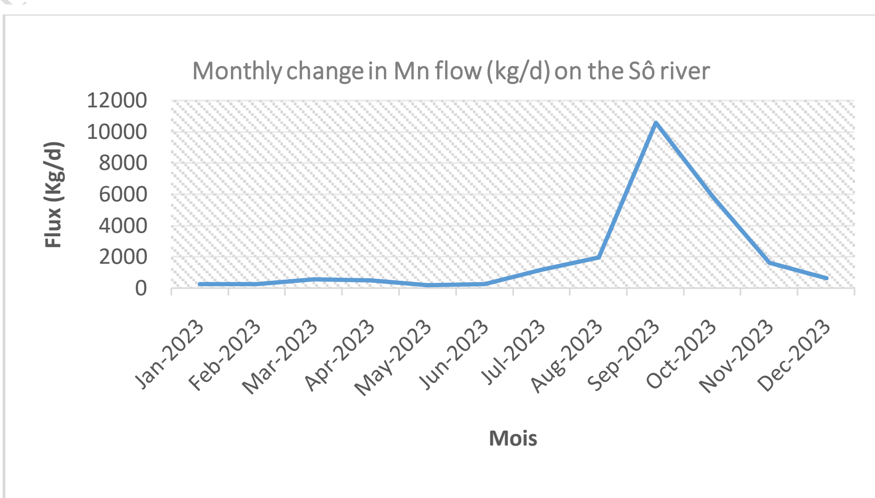


Figure 15: Monthly change in Mn flow (kg/d) on the Sô river

Cadmium flow

The average annual cadmium flow at Sô-Ava is estimated at 328.47 kg/d with a monthly variation of 2.77 kg/d (February) to 1,522.82 kg/d (September). The average flow of cadmium passing through Sô-Ava during the dry period and high water is 87.52 kg/d and 1051.34 kg/d respectively.

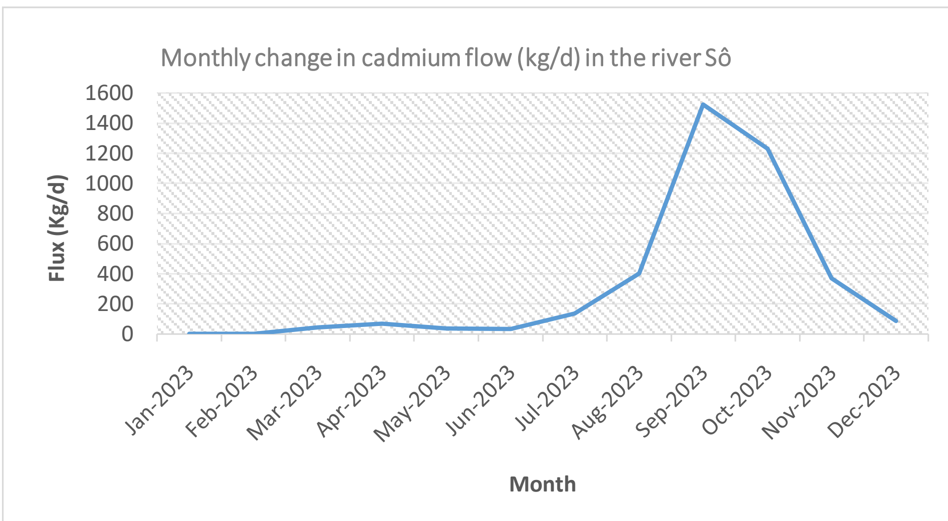


Tableau 6 : estimation of average seasonal and annual flows at the Sô-ava station (S3) on the river Sô

Rivière Sô					
	Min	Max	Average dry season flow	Average high water flow	Average annual flow
NO_3^- -Flux (Kg/d)	103,76	35475,01	802,96	21707,50	6029,10
NH_4^+-Flux (Kg/d)	159,68	30828,072	2146,81	24359,31	7746,81

NT -Flux (Kg/d)	352,29	155303,90	2719,90	70898,03	19764,43
Mn - Flux (Kg/d)	169,09	10560,52	587,11	6129,55	1972,72
Cd- Flux - (Kg/d)	2,77	1522,82	87,52	1051,34	328,47

Discussion

At the level of the two tributaries, the high nitrate flow values (1160.09 kg/d for Djonou and 21707.50 kg/d for the Sô) are obtained during high water periods, which indicates a persistent nitrogen load, due to the excessive use of fertilisers in agriculture but also to domestic discharges or untreated wastewater. The direct impact of a high flow of nitrates on water resources is eutrophication, which will result in an excessive proliferation of algae, as well as an increased consumption of dissolved oxygen during the decomposition of dead algae (Camargo et alonso, 2006). (OECD, 2012). The average annual nitrate flow values obtained for the Sô (6029.10 kg/d) and Djonou (462.47 kg/d) are close to those obtained by Assad in 2014 for the Madon, where average annual nitrate flows were around 3681 kg/d, and to those obtained (3494 T/year) by the Agence de l'Eau Rhône-Méditerranée-Corse, 2003

As for ammonium flows, the highest flows are obtained during high-water periods (24359.31 kg/d for the Sô and 1155.91 kg/d for the Djonou) in the two tributaries, indicating recent organic pollution. Their biological transformation into nitrates consumes oxygen and can acidify the water; they cause acute toxicity for aquatic organisms at low oxygen concentrations and also reduce the pH (acidifying effect) (Garnier et al, 2010). In the long term, they modify the structure of aquatic fauna and disrupt the local food chain (USEPA, 2013). The mean annual ammonium flux values obtained for Djonou (460.44 kg/d) are in line with those obtained for the Madon (806 Kg/d) (Assaad, 2014) and the Hérault (154 T/year) (Agence de l'Eau Rhône-Méditerranée-Corse, 2003). On the other hand, that obtained on the Sô (7746.81 kg/d) is higher than these values, and could be explained by the high flows during high-water periods, but also by the aerobic degradation of organic nitrogen (proteins, amino acids, urea), which comes from untreated domestic wastewater, as sanitation systems are non-existent in most households living within the Sô ava perimeter, forcing them to discharge their waste directly into the river Sô.

Nitrites are unstable intermediate compounds, normally present in small quantities (Lewis et all., 2011). High flow values (730.04 kg/d on average) are obtained during periods of high water in the Djonou River. A large quantity of nitrite in transit towards Lake Nokoué is highly toxic for aquatic fauna and will inhibit the transport of oxygen in the blood of fish ("methaemoglobin" effect) and could also cause an imbalance in the nitrogen cycle (Lewis et all., 2011). The average annual nitrite flow (276.55 kg/d) obtained on the Djonou river is close to that obtained on the Herault (59T/year) by the Agence de l'Eau Rhône-Méditerranée-Corse, 2003

The total nitrogen flow is one of the highest, encompassing all forms of nitrogen (NO_3^-, NH_4^+, organic nitrogen). The highest values (70898.03 kg/d on average) are obtained during periods of high water on the river Sô and this can be explained by chronic and sustained pollution with the corollary of a high potential for lasting eutrophication and a structural imbalance in the ecosystem (Carpenter et all 1998). COD measures the quantity of chemically oxidisable organic matter (Chapra, 1997). High flows (22569.68 kg/d on average) are obtained in periods of high water on the Djonou River and characterise significant organic pollution, resulting in high consumption of dissolved oxygen and destabilisation of the biological balance of the environment (USEPA, 2004). The average annual flow of COD (10595.79 Kg/d) obtained on the Djonou River is much higher than that found by Assaad 2014 (2555 Kg/d) on the Madon River; this could be explained by strong anthropic pressure on the Djonou River, which would generate significant

BOD5 measures biodegradable organic matter. High flows are obtained during high water periods (2703.96 kg/d) and dry periods (4732.99 kg/d) on the Djonou River. These flow values can be explained by a fresh, untreated organic load and contribute to dissolved oxygen depletion and the allotment of aquatic fauna (Richardson, 2003). The average annual flow (4225.73 kg/d) obtained at Djonou is close to the BOD5 load at Ganvié (4147 kg/d) and Sô ava (6220 kg/d) obtained by Mama et all., 2011

Lead is a toxic heavy metal. The highest flows (920.82 kg/d on average) are obtained during high-water periods on the Djonou River. This could be linked to electronic waste (batteries) or fuel residues. Lead poses a threat to aquatic organisms due to its high toxicity and bioaccumulation in the food chain. There is a risk of neurotoxicity and cancer to human health if contaminated fish is eaten (ATSDR, 2020).

Manganese occurs naturally in soils, but high flows (6129.55 kg/d on average) obtained during high-water periods on the Sô indicate excessive solubilisation due to low pH or pollution. It is highly toxic to certain aquatic species. (WHO, 2011)

Cadmium is a highly toxic heavy metal, even at very low concentrations; any repeated detection or abnormally high flux is cause for concern (ATSDR, 2012). On the River Sô, the considerable cadmium flow values (1051.34 kg/d on average) are obtained during periods of high water; this implies chronic toxicity for fish, molluscs and humans through bioaccumulation, and deteriorates the health of aquatic organisms (kidneys, liver, nervous system). (ATSDR, 2012)

This method of estimating flows is subject to temporal and structural errors. The theoretical error is not technically measurable due to the unavailability of daily pollutant concentration records, making it impossible to calculate the actual flow. However, according to Garnier et al. 2010, this flow estimation method remains acceptable because:

● It is simple, robust and reproducible,

● It is justified if concentrations do not vary too much over the month (or in the absence of continuous information),

● It is preferred in contexts where sampling frequency is low, which is common in developing countries or in long-term monitoring.

Conclusion

The approach based on average monthly flow allows for a more robust and realistic estimation of pollution flows. Estimating pollutant flows in the Sô and Djonou rivers, which flow into Lake Nokoué, led to the following conclusions:

The Djonou River is experiencing multiple environmental pressures:

● a high organic load (NH_4^+, BOD5, COD),
● alarming metal pollution (particularly Pb),
● and imbalances in the nitrogen cycle (NO_3^-, NO_2^-).

In the Sô River, nitrogen flows are the most concerning because they indicate sustained and chronic pollution, consistent with significant agricultural or domestic inputs. These results call for:

- Regular monitoring, expanded to other upstream and downstream stations,
- Source reduction measures, particularly for organic and metallic pollution,
- Consultation with local stakeholders (farmers, communities) to limit untreated discharges.
- Regular monitoring, combined with spatial analysis (upstream and downstream, other stations), is essential to guide sustainable water management policies.

BIBLIOGRAPHICAL REFERENCES

1. Agence de l'Eau Rhône-Méditerranée-Corse, 2003. évaluation des flux d'apports polluants à la mediterranée (hors rhône). Dossier M E 02 03 37 (ri) / CT / a
2. ACVDT.,2019**.** Construction du pole agroalimentaire de l'agglomération du grand Nokoué à Abomey Calavi. Rapport d'EIESA.225P
3.
4. Atchichoe, W. N., Dovonou, F. E., Adandedji, F. M.,.& Eninhou, F. S., 2025. Physico-chemical charaterization 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
5. Atchichoe, W. N., Dovonou, F. E., Adandedji, F. M., Dansou, B.& Eninhou, F. S., 2024. Activités anthropiques, sources de pollutions chimiques des rivières Sô et Djonou tributaires du lac Nokoué. European Scientific Journal. ESJ, 20(15), 274. https://doi.org/10.19044/esj.2024.v20n15p274
6. ATSDR (Agency for Toxic Substances and Disease Registry). 2020. Toxicological Profile for Lead.
7. ATSDR (Agency for Toxic Substances and Disease Registry). 2012. Toxicological Profile for Cadmium.
8. **Bénin Topo-foncier**., 2006. Monographie de la commune deSô-Ava.108 p.
9. Camargo, J. A., & Alonso, Á.,2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International, 32(6), 831-849.
10. Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H.,1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(3), 559-568.
11. Chapra, S. C., 1997. Surface Water-Quality Modeling. McGraw-Hill, New York.
12. Diallo, M., 2019. Évaluation de la charge polluante de l'oued Sebou au Maroc. Thèse de doctorat, Université de Fès, Maroc.

13. Direction des pêches, 2004. Rapport Annuel d'Activité Ministère de l'Agriculture, Elevage et Pêche, Bénin.65P
14. EPA.,1986. Estimation of Annual Pollutant Loads to Large Rivers. United States Environmental Protection Agency, EPA/600/3-86/024
15. Garnier, J., Beusen, A., Bouwman, L., & Billen, G., 2010. Nutrient export to European coastal waters: A model-based assessment of spatial patterns in sources and fluxes. Global Biogeochemical Cycles, 24(4).
16. INSAE.,2016. Institut National de la Statistique et de l'Analyse Economique. Effectifs de la population des villages et quartiers de ville du Bénin (RGPH4-2013),85P
17. Kouchade, M.,2002. *Evaluation de la pollution organique et bactériologique due aux excréta, eaux usées et aux déchets solides dans la lagune de Cotonou*. Mémoire DIT / EPAC
18. Lalèyè, P., Niyonkuru, C. Moreau, J. et Teugels, G., 2003. Spatial and seasonal distribution of the ichthyofauna of Lake Nokoué, Benin, West Africa. African Journal of Aquatic Sciences 28 (2): 151-161
19. Lalèyè, P.,1995. Écologie comparée de deux espèces de Chrysichthys, poissons Siluriformes (Claroteidae) du complexe lagunaire « Lac Nokoué-Lagune de Porto-Novo » au Bénin. Thèse de doctorat, Université de Liège, 199p
20. Lewis, W. M., Morris, D. P., & Titus, J. E.,2011. Toxicity of nitrite to aquatic life. Journal of Environmental Quality, 30(2), 377-388
21. Mama, D.,2010. Méthodologie et résultats du diagnostic de l'eutrophisation du lac Nokoué (Bénin). Mémoire de Thèse de l'Université de Lausanne, 157p.
22. Mama, D., Aina, M., Alassane, A., Boukari ,O. T., Chouti, W., Deluchat, V., Bowen, J., Afouda, A. et Baudu, M., 2011. Caractérisation physico-chimique et évaluation du risque d'eutrophisation du lac Nokoué (Bénin). Int. J. Biol. Chem. Sci. 5(5): 2076-2093, October 2011. http://ajol.info/index.php/ijbcs
23. OECD .,2012. Water Quality and Agriculture: Meeting the Policy Challenge
24. Richardson, S. D.,2003. Water analysis: Emerging contaminants and current issues. Analytical Chemistry, 75(12), 2831-2857.
25. Roche Internationale, 2000. Etude du projet d'aménagement des plans d'eau du Sud-Bénin. Synthèse de l'état des lieux et cadre de développement, volume I. 87 p.
26. Rodier, J., Legube, B., Merlet, N., 2009. L'analyse de l'eau, eaux naturelles, eaux résiduaires, eau de mer, chimie, physico-chimie, microbiologie, biologie, interprétation des résultats (9th éd). Paris: Dunod.
27. Senouvo, P., 2002. Etude de l'impact des pollutions en métaux lourds (plomb, cuivre et zinc) sur l'écologie des huîtres Crassestrea gascar en zones urbaines du lac Nokoué et du chenal de Cotonou (Bénin). Mémoire de DEA en Gestion de l'environnement FLASH/UAC, 64p
28. Seriki, S. A., 2018 .Pollution des eaux et vulnérabilités des ressources halieutiques de la rivière So dans la commune de SO-AVA, Journal de la recherche scientifique de l'université de Lomé, 17P
29. Tossou, S., 2000. Impact du trafic des produits pétroliers sur les écosystèmes lacustres : Cas du lac Nokoué et de la lagune de Cotonou (Bénin). Mémoire de DEA en Gestion de l'environnement FLASH / Université d'Abomey-Calavi, 132 p.
30. USEPA. 2004. Guidelines for Water Reuse
31. WHO (World Health Organization). 2011. Manganese in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality.