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Impact of road construction on Ouémé river pollution using biodegradability index and organic pollution index: Case of road Akpro-Misséréte / Kpédékpo in Benin

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Abstract: The Ouémé River is the largest river in Benin Republic. It is strongly influenced by the tropical wet and dry precipitation seasonality. Due to its length and its large basin, it is an essential ecosystem for the local population and eventually faced environmental stresses, notably pollution. This study aims to assess the impact of road construction on river pollution. A total of 12 water samples were taken at 6 stations over two field campaigns, one in march 2025 and the other in August. Water temperature, pH, Dissolved oxygen and Turbidity were measured in situ. Ammonium, Nitrite and Phosphate concentrations were measured using a Spectrophotometer, Chemical Oxygen Demand using potassium dichromate method and Biochemical Oxygen Demand using the respirometric method. The Organic Pollution Index (OPI) was calculated to assess the level of organic pollution. The results showed very strong pollution index (1.5-1.9) in high-water regime and showed strong pollution index between (2-3) in low-water regime except for the station of Gotin (R1). The biodegradability was assessed to confirm the origin of this organic pollution, The results show that the biodegradability of this pollution is slow in some places and not biodegradable in other places. These results confirm that the source of organic pollution is not domestic but rather industrial, as in the case of road construction along this watercourse. These results will help the managers of this river to take appropriate measures for its layout and restoration, with a principal view to its sustainable management.

1. Introduction

The health of aquatic ecosystem depends on minimum standards for water quality, defined to guarantee sufficient dissolved oxygen (DO) concentrations (> 5 mg/L) and limited phosphorus and nitrogen concentrations (Le et *al.,* 2010). Reduced water quality is often first visible in higher turbidity caused by light scattering coming from particles present in the water column. Turbidity increases the temperature of water, which can then hold less oxygen. Oxygen is further reduced when eutrophication resulting from excess phosphorus and nitrogen input causes an algal bloom that consumes the oxygen (Correll, 1998; Hobbie et *al.*, 2017; Patil & Deng, 2012). The effects of water quality impairment on food chains, including benthic macroinvertebrate and fish communities, are often immediate and profound (DaSilva et *al.,* 2013; Hassan et *al.*, 2015; Nasri et *al.,* 2024). Construction activities and hydromodification are recognized as major sources of water quality impairment in urban streams, because they increase sediment input into waterways and downstream aquatic ecosystems (Brabec et *al.,* 2002; Chen et *al.,* 2009; Meyer et *al.,* 2005). Highway construction can lead to a rapid decline in stream water quality (e.g., suspended solids, iron, chloride, sulfate, nitrogen, and pH), not only during construction but also in the period that follows (Chen et *al.,* 2009; Purcell et *al.,* 2012). The pollution from this type of large construction projects degrades aquatic ecosystems and has severe impacts on food webs (Bennett et *al.,* 2001). Evidence suggests that aquatic ecosystems in small streams are equally susceptible to pollution by sediment (Lemly, 1982; Belbachir *et al.,* 2013); however, the local water quality impacts in these small streams are extremely variable (Berger et *al.,* 2017). In Benin, Ouémé is the longest river, and its delta extends to nearly 90 km with a fairly large flood zone of more than 9000 km^2 (Kodja et *al.,* 2018). This delta zone is located on sedimentary soil loaded with alluvium, which is transported from upstream of the river, and hosts a diversity of plant communities (Houngue, 2020). The study of water quality in the Delta Ouémé River is necessary since many human activities taking place within its watershed causing anthropogenic stress to environment. Intensive sand extraction, domestic effluent discharges, construction of roads and dams are among the main disruptions affecting water quality and stream morphology of this River. This is the rationale behind this study, whose overall objective is to assess the spatio-temporal dynamic of organic pollution in the Ouémé river due to road construction activities.

2. Methodology

2.1 Study area

The Ouémé River is the largest river in Benin Republic. Its geographical location spans between approximately 6°30' and 10° north latitude and 0°52' to 3°05' east longitude. The river takes it source in the Tanéka Mountains in the Atacora Department and is fed by two main tributaries: the Okpara River (200 km long) and the Zou River (150 km long) (Kodja et *al.*,2018). The river crosses several agro-ecological zones and ultimately feeds the lagoon system known as the Lake Nokoué–lagoon of Porto-Novo through a delta zone. The lower delta of the Ouémé, which is the focus area of our study, lies between latitudes 6°33'N and 8°15'N and longitudes 1°50' and 2°00'E (Zinsou et *al.,* 2016). The lower Delta of Ouémé begins after municipality of Adjohoun in the department of Ouémé and ends at the south facade where the river flows into the Nokoué–Porto-Novo lagoon complex. Climatically, the area is influenced by a subequatorial climate with two rainy and two dry seasons. The hydrological dynamics follow a Sudanian climate pattern from northern Benin, featuring a low water period lasting about seven months (November to June) and a flood period from July to October (Kodja et *al.,* 2018). Vegetation along the river includes swampy areas with floating plants such as water hyacinth (Eichhornia crassipes), water lily (Nymphaea lotus), water lettuce (Pistia stratiotes), and duckweed (Lemna pairciostata). There are also undeveloped marshy forests dominated by raphia palm (Raphia hookeri) and oil palm (Elaeis guineensis). The water-covered parts of the valley are noted for their high fish productivity (Zinsou et *al.,* 2016).

2.2 Sampling plan

The water samples, for the determination of rivers organic pollution, were collected from the selected sampling locations Gotin (R1), AdjohounAv (R2), BonouAv (R3), BonouAm (R4), KpédékpoAv (R5) and KpédékpoAm (R6) of the stretch of Ouémé River for Low water (March - Avril) and high water (August - September) periods in the year 2025. The choice of sites is made by considering the density of the riparian population, human activities in the surrounding area and in the watercourse, the boundaries of villages, and the scope of each sampling site. The samples were collected at 10–15 cm depth in separate pre-conditioned and acid rinsed clean 500-ml polypropylene bottles. Each water sample was acidified with 1 mL of concentrated nitric acid (HNO3) to preserve trace elements in their ionic form (Rodier, 2009). The water samples were then properly stored in coolers with ice packs (4°C) and transported to the laboratory for analysis. All sampling procedures followed the guidelines of the French Association for Standardization (AFNOR) (Rodier, 2009).

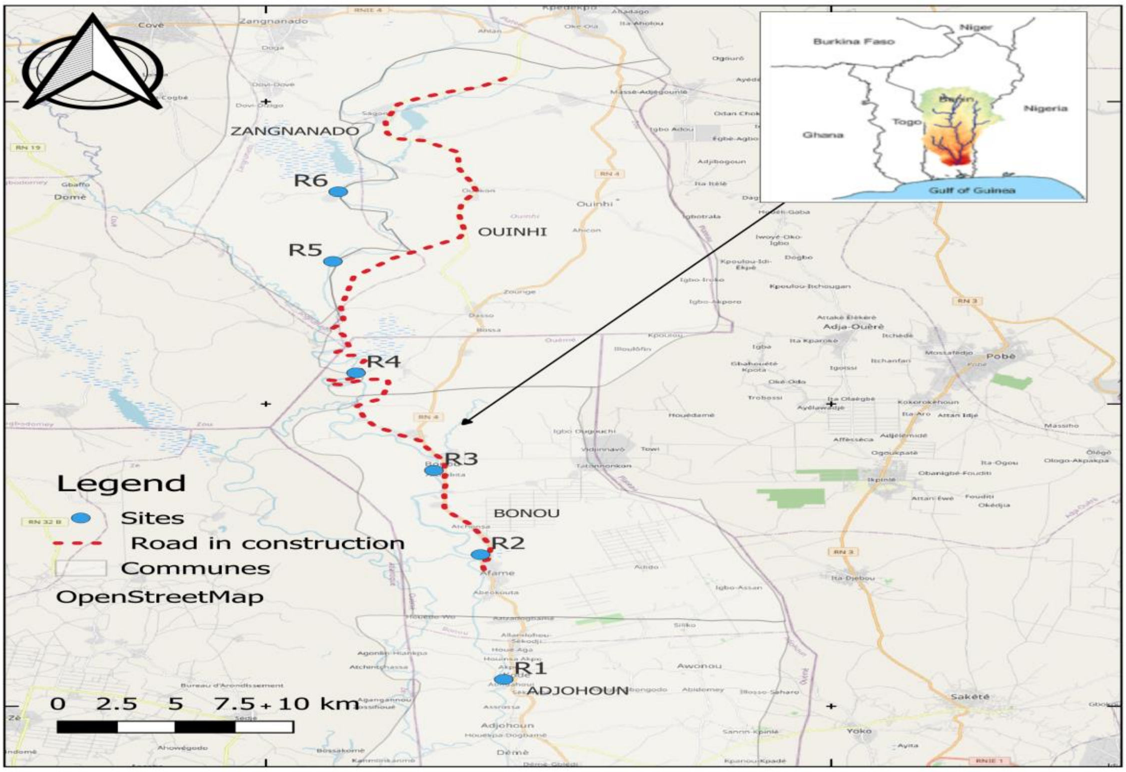

Figure 1. Study area and sampling stations

2.3 Water physicochemical characterization

For the field activities, we used a motorized boat, water samples were taken from various sampling points using 1.5 liters plastic bottles that had been rinsed before use. After sampling and before being kept cool in the cooler, each sample was labelled with the name of the stations and the date and time of sampling. The physicochemical parameters of the water, such as water temperature, pH, Dissolved oxygen and Turbidity, were measured in situ using a Secchi disk, a multi-probe meter HANNA HI 9829 and a WTW Cond 3310 SET 1 (2BA301). Measurements and sample collection were carried out according to the protocol developed by (Rodier *et al.*, 2009) used by (Odountan *et al.*, 2019). After the fieldwork, the water samples taken were transported to the Laboratory of Applied Hydrology (LHA) at National Water Institute (NWI) of University of Abomey-Calavi and stored in a refrigerator for subsequent analysis. Nutrients such as Ammonium, Nitrite, Nitrate, Orthophosphate and total Phosphorus were measured no more than 48 hours after sampling using a molecular absorption spectrophotometer HACH DR 6000 at an appropriate wavelength, using the appropriate method for each parameter (**Table 1.**). The Biochemical Oxygen Demand (BOD5) was assessed using the OxiTop respirometric method in a thermostatic chamber (or BOD meter) at 20°C for five days.

Table 1. Methods used to measure the nutrients and Biochemical Oxygen Demand of water

Designations	Analysis methods
$NH4^+$ (mg/L)	Nessler reagent spectrophotometer assay method Nitrates
$NO2^-$ (mg/L)	Nitriver 3 reagent spectrophotometer assay method
PO_4^{3-} (mg/L)	PhosVer 3 reagent spectrophotometer assay method
BOD5 (mg/L)	Respirometric (or manometric) method

2.4 Data processing

The data was analyzed firstly by calculating the mean and standard deviation of the various physico-chemical parameters selected and identify the minimum and maximum values, according to the sampling stations in dry and wet season. The calculated averages were then compared using ANOVA at the 5% significance level (Mangiafico, 2015). The trend of Organic Pollution Index (OPI) and Biodegradability Index (BI) is based on water quality data in the dry and rainy seasons. The results of the analysis are then used to describe the organic pollution problems in the Ouémé River due to road construction activities. We performed the Organic Pollution Index (OPI) estimation, which indicates the degree of alteration of water by chemical variables revealing the organic pollution of an ecosystem, was calculated using parameters such as Ammonium, Nitrite, Phosphate and Biochemical Oxygen Demand (BOD5), which are nutrients linked to organic pollution according to (Leclercq, 2001). It was calculated by first assigning a status class to each nutrient, taking into account the defined class limits, and then averaging the class numbers taken by these four nutrients at the same sampling station. The OPI is calculated using the following formula, its value varies from 1 to 5 and its interpretation is given in Table 2.

Eqn. 1 $$OPI = \frac{\sum_{i=1}^{n} C_i}{n}$$

With C_i is the class number of the nutrient and n the number of nutrients retained.

Table 2. Class limits for calculating the Organic Pollution Index and level of pollution (Leclercq, 2001).

Classes	DBO5 (mg/L)	NH_4^+ (mg/L)	NO_2^- (µg/L)	PO_4^{3-} (µg/L)	OPI	Levels of pollution
5	< 2	< 0,1	< 5	< 15	4.6 - 5	Very Weak
4	2 - 5	0,1 – 0,9	6 – 10	16 – 75	4 – 4.5	Weak
3	5,1 - 10	1 – 2,4	11 – 50	76 – 250	3 – 3.9	Moderate
2	10,1 - 15	2,5 - 6	51 – 150	251 – 900	2 – 2.9	Strong
1	> 15	> 6	> 150	> 900	1 – 1.9	Very Strong

In addition, BI value is calculated by comparing BOD5 and COD parameters. The BOD5/COD ratio value > 0.6 indicates that the pollutants in the waters are included in the biodegradable category. The slow-biodegradable category includes the water pollutants for the BOD5/COD ratio of 0.3 - 0.6. In contrast, for the BOD/COD ratio < 0.3, they are included in the non-biodegradable category (Tamyiz, 2015). The data processing and statistical analysis, as well as for generating graphs and multivariate statistical analysis were carried out using Python and R programming language. Principal Component Analysis (PCA) was performed using the FactoMineR and factoextra packages in R, as described by (Lê et *al.*, 2008). PCA was employed to emphasize the associations among the different trace metals analyzed and to explore patterns in water resources concerning these elements. The applicability of this exploratory technique relies on selecting the number of factor axes that represent the maximum amount of inertia while retaining the fewest possible factors. Generally, PCA for a region is considered valid when the factor planes retain at least 70% of the information (Attingli et *al.*, 2017). Below this threshold, it is considered that the study of the region has not accounted for a substantial amount of information.

3. Results and Discussion

3.1 Water physicochemical characterization

The results presented in **Tables. 3** show that the physicochemical parameters of the water fluctuated according to the sampling stations. Apart from pH and dissolved oxygen, the other parameters studied showed very significant variations at all of our study stations R1 to R6 (p value<0.05). The highest mean values of temperature (28.35 ± 0.35 °C), pH (7.20 ± 0.00) and COD (74.00 ± 0.00 mg/L) were found at Bonou-Avale (R4), and the lowest values were obtained at the Kpédékpo-Amont (R5) (26.90 ± 0.71 °C) and Gotin (R1) (6.49 ± 0.05 and 13.00 ±1.41mg/L) respectively. The highest mean values of turbidity (72.00±2.83 NTU), Nitrite (4.398 ± 0.71 mg/L), Ammonium (4.060 ± 1.33 mg/L), TPH (0.1790 ± 0.01 mg/L) and Phosphate (0.1790 ± 0.01 mg/L) were found at Adjohoun-Avale (R2), while the lowest value was found at Gotin (R1) (24.00 ± 1.41 NTU, 0.095 ± 0.01 mg/L, 0.257 ± 0.02 mg/L, 0.0034 ± 0.01 mg/L) and Kpedékpo-Avale (R6) (0.216 ± 0.14 mg/L) respectively. The highest value of BOD5 (27.00 ± 0.00 mg/l) was obtained at Kpedékpo- Avale (R6) and the lowest value 13.00 ± 1.41 at Gotin (R1).

The results on the physicochemical parameters of the water in the Ouémé river showed significant variations depending on the sampling stations for most parameters, in particular COD, turbidity, phosphate, ammonium, nitrite, BOD5 and TPH. The results reveal that the pH values obtained 6.5 ≤ pH ≤ 8.5, regardless of the period, comply with WHO standards. The significant spatial variations recorded between the stations for COD, turbidity, phosphate, ammonium, nitrite, BOD5 and TPH could be explained by the internal organic load and the level of disturbance at each station, where the decomposition of biomass, more specifically water hyacinth and organic waste, and the input of inorganic pollutants lead to oxygen consumption, an increase in nutrient concentration and Biochemical Oxygen Demand. A comparison of the results of this study with those obtained by (Sintondji et *al.*, 2022) shows that they follow the same trend, although the mean values obtained are different. The highest turbidity values are obtained during the rainy season. One of the causes of increased turbidity was the materials used for road construction, such as coarse sand, then the soil erosion during rain, limiting light penetration and disrupting photosynthesis in aquatic organisms. This is confirmed by (Grimm et *al.*, 2024), these authors showed a strong correlation between increasing of turbidity and rainfall intensity. This high turbidity recorded at Adjohoun-

Avale (R2) may reflect also agricultural runoff or domestic pollution in this area, aligning with observations from (Laleye et *al.,* 2004) and (Zinsou et *al.,* 2016) indicating the influence of land use on water quality in the Ouémé delta. The increase in nitrite concentration during high water periods at all sites except the control site (R1) can be explained by the leaching of disturbed soils and bituminous materials, which promotes the release of ammoniacal nitrogen into the water. This is converted into nitrites by nitrifying bacteria, contributing to eutrophication and the degradation of water quality, this result followed the same trend with those obtained by (Lingofo et *al.,* 2025). Indeed, domestic urban waste directly discharged into the river by populations living on stilts, and urban runoff cause large variations in this component, particularly after the withdrawal of water from the rainy season (Alhou et *al.,* 2009; Zirirane et *al.,* 2015). This assertion is corroborated by current research and confirms that urban runoff from the road under construction contributes to river pollution. The same increasing is observed in phosphorus where the high value is observed in high-water period. The seasonal dynamics of river water quality show a phosphorus release linked to organic matter mineralization during low water period (December–May) and an increased load of inorganic nutrients during high water period (August–November), according to (Mama et *al.,* 2011; Odountan et *al.,* 2019). Similarly, the high value obtained for COD and BOD5 in high and low water period above WHO standards (WHO, 2011) increase the pollution load of organic matter in surface waters. This confirms the work of (Alagbe et *al.,* 2014) who referred to the high organic matter content that can disturb the development of aquatic life in the watercourses of Ngaoundéré, Cameroon. The surface water of the lower valley also presents a quasi-persistent presence of BOD5. This is in line with the work of (Attingli et *al.,* 2017) who have shown that this parameter does not depend on the hydrological cycle but on the fishing zones. According to (Dovonou et *al.,* 2024) the waters of the Lake Ahémé-Gbézounmè lagoon complex in Benin have very high mineral contents such as nitrite, nitrate and phosphate as well as COD and BOD5 concentrations in the water samples analysed.

3.2 Spatial variation of organic pollution as a function of hydrological regimes

The spatial variation of organic pollution index as a function of hydrological regimes is shown in Figure 2. The result showed that very strong pollution levels were observed at all the stations during the high-water regime except for Gotin (R1) station which is the control station showed the moderate pollution during the low-water regime but in high-water regime, this pollution level became strong. In the low-water regime, only Adjohoun-Avale (R2) has strong pollution levels. All other remaining stations show a strong pollution index during the low-water period. The pollution level of all these stations had increased during the high-water regime. The pollution level of all these stations had increased during the high-water regime. **Figure 3.** shows that nitrite, phosphorus and biochemical oxygen demand are parameters that influence the level of pollution in this complex. Moreover, it was observed that phosphorus and nitrite had a considerable influence during the low-water and high-water regimes. That influence is observed at station R2 particularly. The results of the assessment of organic pollution showed the increasing of organic pollution index at all of the stations during the high-water period.

Table. 3 Spatial variations of the physicochemical parameters.

parameters	stats	R1	R2	R3	R4	R5	R6	p-value	Sign
Temperature (∘C)	Min-Max	27.5-27.8	27.6-27.7	28.0-28.3	28.1-28.6	26.4-27.4	26.7-27.4	0.038	yes
	Mean±sd	27.65±0.21	27.65±0.07	28.15±0.21	28.35±0.35	26.90±0.71	27.05±0.49		
pH	Min-Max	6.45-6.52	7.10-7.15	6.90-7.10	7.20-7.20	7.10-7.13	6.80-7.14	0.198	no
	Mean±sd	6.49±0.05	7.13±0.04	7.00±0.14	7.20±0.00	7.12±0.02	6.97±0.24		
DO (mg/L)	Min-Max	6.19-6.76	6.15-6.50	6.26-6.86	6.27-6.70	6.74-6.94	6.78-7.00	0.192	no
	Mean±sd	6.48±0.40	6.33±0.25	6.56±0.42	6.49±0.30	6.84±0.14	6.89±0.16		
Turbidity (NTU)	Min-Max	23-25	70-74	39-41	51-57	43-48	60-63	0.01	yes
	Mean±sd	24.00±1.41	72.00±2.83	40.00±1.41	54.00±4.24	45.50±3.54	61.50±2.12		
Nitrite (mg/L)	Min-Max	0.090-0.100	3.898-4.898	0.110-0.200	0.109-0.409	0.172-0.298	0.167-0.267	0.02	yes
	Mean±sd	0.095±0.01	4.398±0.71	0.155±0.06	0.259±0.21	0.235±0.09	0.217±0.07		
Ammonium (mg/L)	Min-Max	0.242-0.272	3.120-5.000	0.341-0.464	0.340-0.400	0.256-0.600	0.300-0.500	0.01	yes
	Mean±sd	0.257±0.02	4.060±1.33	0.403±0.09	0.370±0.04	0.428±0.24	0.400±0.14		
Phosphate (mg/L)	Min-Max	0.056-0.556	1.569-1.569	0.089-1.200	0.082-0.982	0.117-0.417	0.116-0.316	0.03	yes
	Mean±sd	0.306±0.35	1.569±0.00	0.645±0.79	0.532±0.64	0.267±0.21	0.216±0.14		
COD (mg/L)	Min-Max	14 - 12	38-41	53-55	74-74	67-67	73-75	0.01	yes
	Mean±sd	13.00±1.41	39.50±2.12	54.00±1.41	74.00±0.00	67.00±0.00	74.00±1.41		
BOD5 (mg/L)	Min-Max	04-06	13 - 11	21-23	25-25	25-23	27-27	0.01	yes
	Mean±sd	5.00±1.41	12.00±1.41	22.00±1.41	25.00±0.00	24.00±1.41	27.00±0.00		
TPH (mg/L)	Min-Max	0.0017-0.005	0.1740-0.184	0.0042-0.006	0.0284-0.038	0.0068-0.072	0.0800-0.0828	0.02	yes
	Mean±sd	0.0034±0.01	0.1790±0.01	0.0052±0.01	0.0334±0.01	0.0070±0.00	0.0814±0.00		

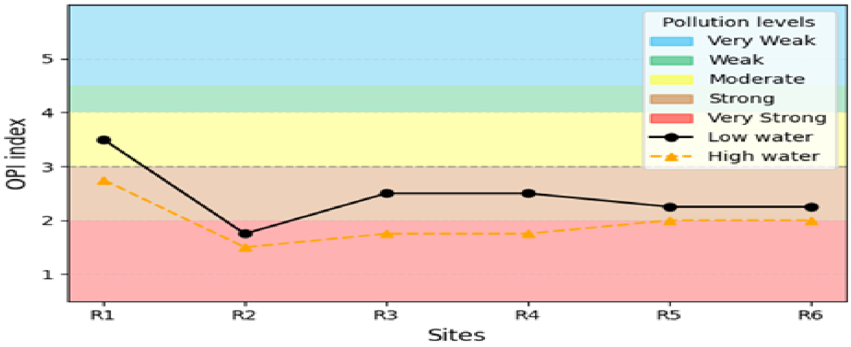

Figure 2. Spatial variation of organic pollution

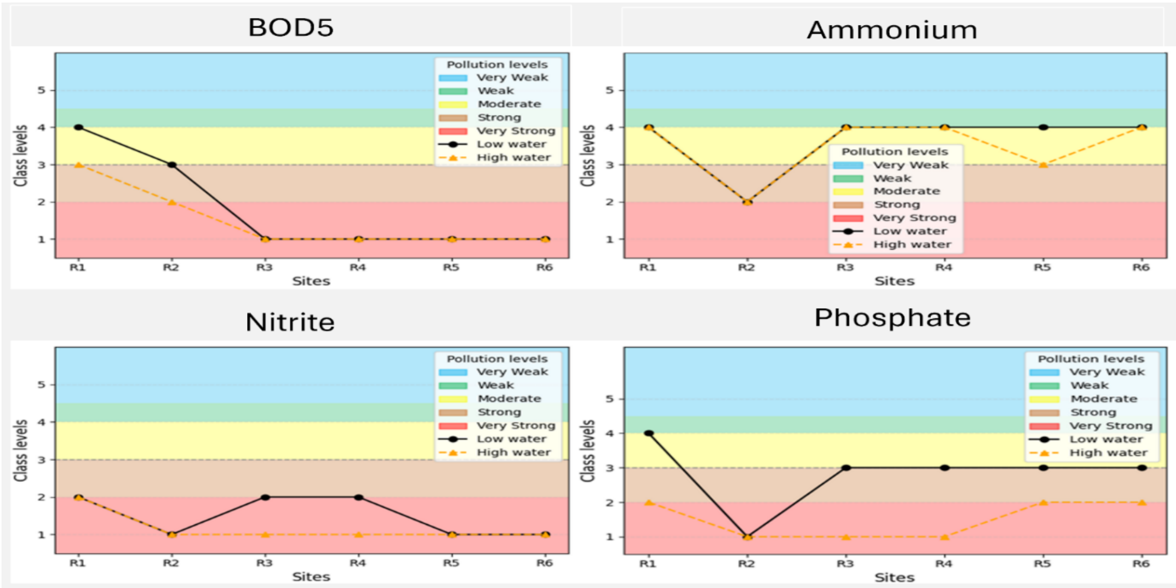

Figure 3. Spatial variation of chemical parameters used to evaluate the organic pollution

The results presented in **Tables 4.** show the biodegradability index (BI) of the water according to the sampling stations. Based on this result, a key finding is the general consistency of the biodegradability index (BI) across most stations, though with notable differences in status. Stations R1, R5, and R6 consistently show a slow biodegradable (SB) status for organic matter during both low-water and high-water seasons, indicating a stable, moderate degradation rate. In contrast, stations R3 and R4 are consistently classified as non-biodegradable (NB) throughout the year. Station R2 presents a unique case with a seasonal shift: its organic matter is non-biodegradable (NB) during the low-water season, but shifts to slow biodegradable (SB) during the high-water period. Overall, this table reveals a clear spatial variation in biodegradability, with some sites dominated by non-biodegradable material while others exhibit a stable, albeit slow, degradation process.

The highest pollution index during low-water (3.5) is observed at R1 (Gotin) with moderate pollution status, can be linked to status of this site (R1) with is our control site, this supposed to not be polluted by road construction activities. Most other stations (R3 to R6) show strong pollution indices (2 to 2.5) during low-water, which tend to somewhat decrease in the high-water period, indicative of dilution effects from increased flow. Station R2 shows a contrasting pattern with slightly higher pollution during high water, which may reflect distinct land use impacts and urban runoff from road construction site near the river effect. The change observed from very strong pollution in low-water period to strong pollution, stations (R2 to R6) during the high-water regime could be linked to the dilution of Phosphate and Biochemical Oxygen Demand at these stations. A similar seasonal and spatial distribution was observed by (Lawani et *al.,* 2016) in the Ouémé River, where organic pollution peaked during high-water periods due to runoff carrying organic waste, but some stations closer to pollution sources exhibited consistent strong pollution throughout the year. In they work (Lalèyè et *al.,* 2004) found comparable patterns where organic pollution indices were highest during the dry season (low-water), attributed to reduced dilution capacity, while flood periods brought dilution but also transported additional organic input from surrounding agricultural lands and settlements. The level of slow-biodegradable and non-biodegradable degradation in all of our site can be caused by the non-point-source sector originating from agricultural land due to pesticides and chemicals urban runoff, which include organic compounds (Hermawan et *al.,* 2023). The non-biodegradability of this organic water pollution at all sites except the Gotin control site (R1) is linked to the fact that the source of this pollution is industrial, probably originating from road construction sites. This is because organic pollution of domestic origin is easily biodegradable (Ayele et *al.,* 2023).

Table 4. biodegradability index

Sites	Season	BI	Status
R1	Low-water	0.33	SB
	High-water	0.43	SB
R2	Low-water	0.26	NB
	High-water	0.32	SB
R3	Low-water	0.22	NB
	High-water	0.20	NB
R4	Low-water	0.23	NB
	High-water	0.25	NB
R5	Low-water	0.37	SB
	High-water	0.34	SB
R6	Low-water	0.37	SB
	High-water	0.36	SB

SB: Slow Biodegradable; NB: No Biodegradable; BI: Biodegradability index

3.3 Inter-pollutant relationships in river water based on Pearson's correlation coefficients

The relationship between the variables, along with the corresponding correlation coefficients, are presented in the correlation matrices shown in **Figure 4A.** and **Figure 4B.** for the low-water and high-water periods, respectively. A stronger correlation between two variables is indicated by a darker blue color. According to the adopted representation model, analysis of **Figure 4A.**, which pertains to the low-water period, reveals a strong positive correlation is observed between

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD5) (99%). Turbidity shows a significant positive correlation with Nitrite (64%), Ammonium (64%), and Phosphate (64%), suggesting that an increase in suspended solids is associated with higher levels of these nutrients. Similarly, Total Petroleum Hydrocarbons (TPH) is also strongly correlated with Nitrite, Ammonium, and Phosphate (89%) which indicates that common input sources of these parameters as well as their similar geochemical characteristics (Mishra et *al.,* 2015). Conversely, temperature is negatively correlated with DO (−72%) and pH (−32%), which is typical as colder water holds more dissolved oxygen. During the high-water season (B), the relationships among parameters shift. While the strong positive correlation between COD and BOD5 remains (97%), the relationship between other parameters changes. Temperature exhibits a weak negative correlation with DO (−55%) and a positive correlation with pH (19%). A notable finding is the strong negative correlation between dissolved oxygen (DO) and both Nitrite and Ammonium (−79% and −0.76%, respectively), suggesting that higher levels of these nitrogen compounds lead to a significant depletion of oxygen. Furthermore, Ammonium and Nitrite show a very strong positive correlation with each other (73%), and with turbidity (69% and 69%, respectively), TPH shows a weaker correlation with nutrients, but a strong positive correlation with turbidity (86%), suggesting that during low flow

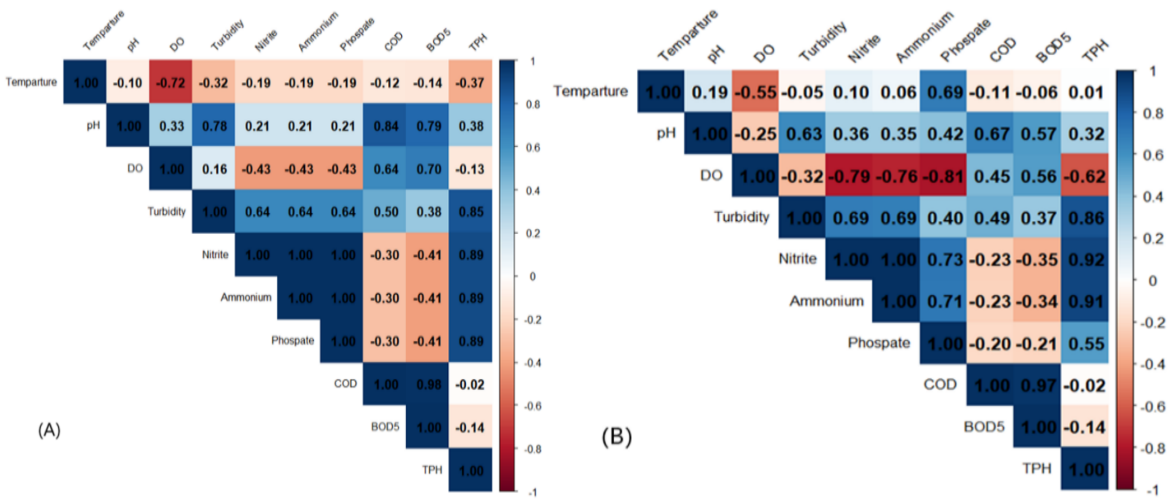

Figure 4. Pearson correlation between chemical elements during the low-water period (A) and the high-water period (B).

3.4 Principal Component Analysis (PCA)

Multivariate analysis of the dust samples was per formed through principal component analysis (PCA). PCA is designed to reduce the number of variables to a small number of indices (i.e. principal components or factors) while attempting to preserve the relationships presented in the original data. The number of significant principal components was selected on the basis of the Kaiser criterion with the eigenvalue being approximately 1 or higher (Kaiser, 1960). In our data and according to this criterion, only the first two principal components were retained. The Figure 5A and 5B present the percentages of variance explained by each principal component, for the low-water and high-water periods, respectively. According to the results presented in **Figure 5.**, the variability explained by the first two principal components of the PCA during both the high-water and low-water periods remains below 75%. The factor plane (Dim1 × Dim2) explains 84.9% of the variance during the low-water period and 79.8% during the high-water period, consequently these two factors are retained.

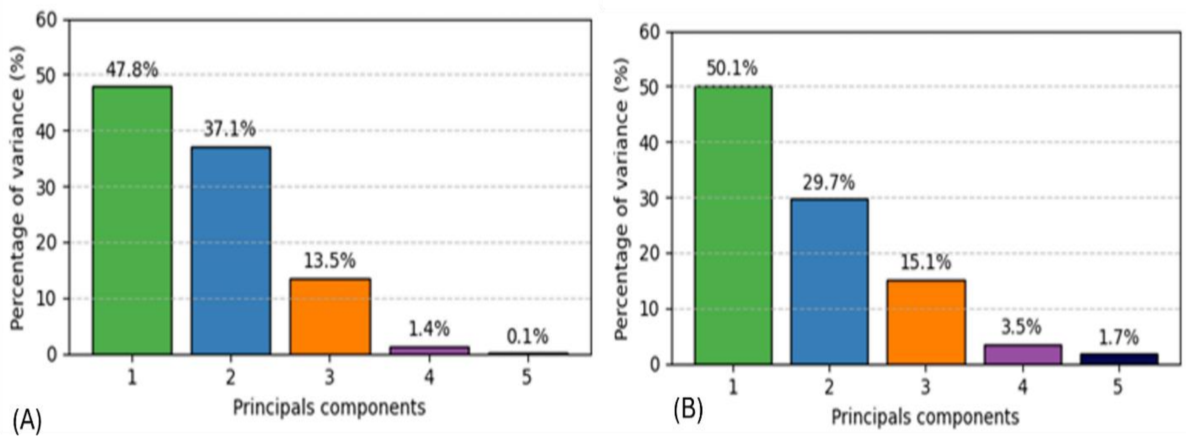

Figure 5. Percentage of variance explained by each com ponent during the low-water period (A) and the high-water period (B).

The factor plane (Dim1 × Dim2) explains 84.9% of the variance during the low-water period and 79.8% during the high-water period, consequently these two factors are retained. The **Figure 6A.** and **Figure 6B.** illustrate the relationships between water quality parameters during different seasons. In the low-water season (**Figure 6A.**), the first principal component (Dim1), accounting for 47.8% of the variance, is strongly driven by a cohesive group of variables: Turbidity, TPH, Nitrite, Phosphate, and Ammonium. The close proximity and long vectors of these parameters indicate a strong positive co-variation, suggesting a common origin of pollution. A second distinct cluster is formed by COD, BOD5, and DO, which are strongly correlated with Dim2 (37.1% of variance). Temperature is notably positioned in the opposite direction from these three variables, highlighting its inverse relationship with organic matter and dissolved oxygen levels. During the high-water season (Figure 6B), the data structure remains largely similar but with subtle shifts. Dim1, explaining 50.1% of the variance, is once again dominated by the same pollution-related cluster of Turbidity, TPH, Ammonium, Nitrite, and Phosphate. Their strong projection on this axis confirms their collective behavior. COD and BOD5 form a separate group, strongly correlated with Dim2 (29.7% of variance), which indicates that organic matter dynamics constitute a second primary source of variation. The position of the Temperature vector shifts, suggesting a different influence on the overall system compared to the low-water season. The clear separation between the pollutant and organic matter clusters reinforces the notion of two distinct processes governing water quality in both seasons.

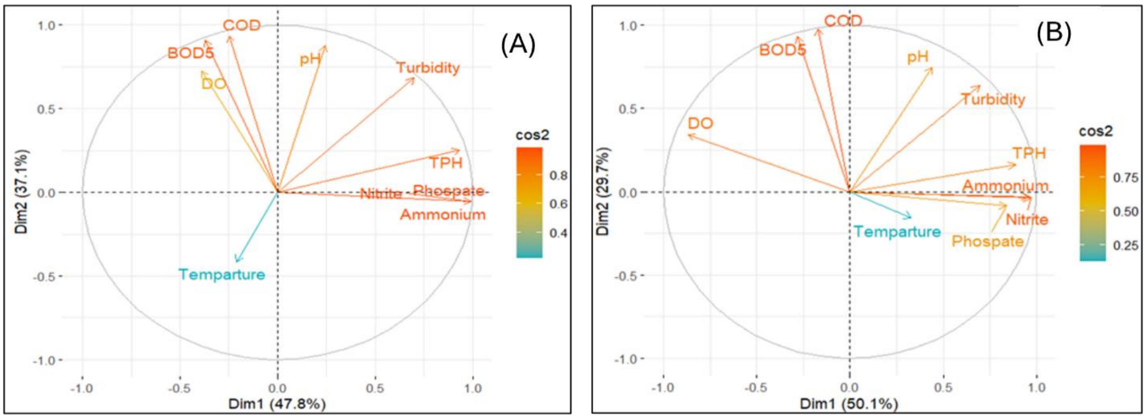

Figure 6. Factorial variables in the F1 × F2 space during the low-water period (A) and the high-water period (B)

Figure 7 showed the biplots of the principal component analysis (PCA) results for both high-water (A) and low-water (B) seasons, plotting both variables and sampling sites. In the high-water season (A), Dim1, which accounts for 50.1% of the total variance, is strongly defined by a cluster of pollution-related variables including Turbidity, TPH, Ammonium, Nitrite, and Phosphate. The sites AdjouhounAv (R2), BonouAv (R4), and BonouAm (R3) are projected in the same quadrant as these variables, indicating that they are heavily influenced by this type of pollution during high-flow conditions. Conversely, sites such as Kpedekpo (R5, R6) and Gotin (R1) are positioned closer to the vectors for COD, BOD5, and DO, suggesting that organic matter and oxygenation dynamics are the dominant characteristics at these locations. The low-water season (B) presents a similar structure with Dim1 (47.8% of variance) again being positively correlated with the same pollution cluster of TPH, Turbidity, Nitrite, Ammonium, and Phosphate. The projection of sites confirms a clear spatial pattern: AdjouhounAv (R2) and BonouAv (R4) are consistently located within the quadrant of these pollutants, identifying them as the most affected sites in both seasons. Conversely, Kpedekpo (R5, R6) and BonouAm (R3) are aligned with the COD, BOD5, and DO vectors, highlighting the dominant influence of organic matter at these sites. The consistent grouping of both variables and sites across seasons suggests that the sources of pollution and the distinct water quality characteristics of the different sampling locations remain stable regardless of the hydrological regime (Vigiak *et al.*, 2019; Saidia *et al*., 2023).

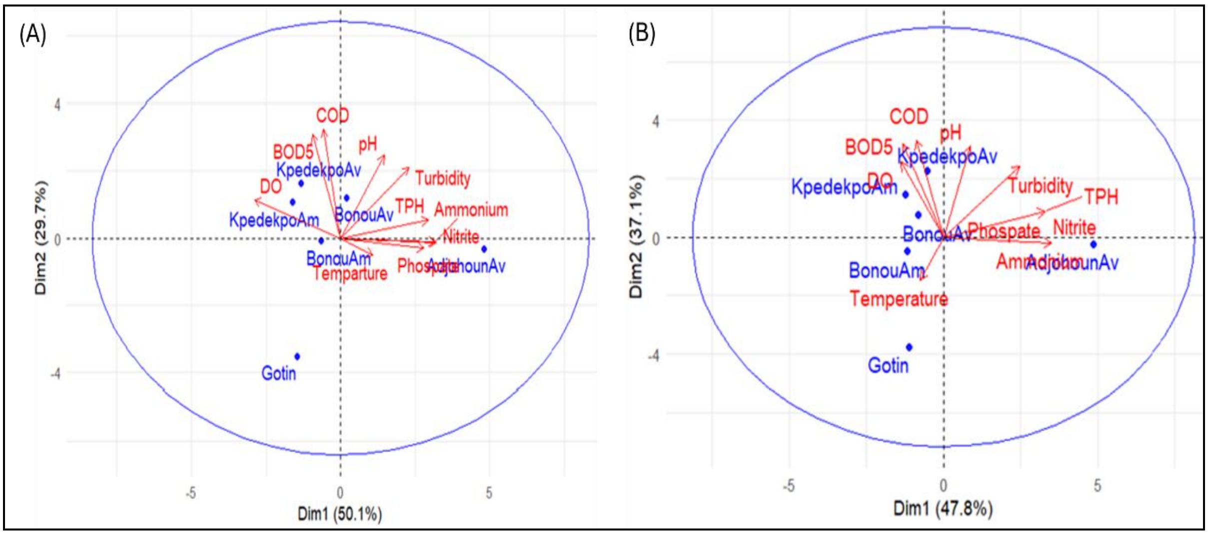

Figure 7. Biplot of principal component analysis factors, F1and F2 for all the parameters.

The varying factors obtained from PCA indicate that the physicochemical responsible for water quality variations are mainly related to the flow of river water (Mishra et al., 2015a). The pollution source seems to be significantly due to natural, the major anthropogenic sources, industrial and urban discharges (Zarei and Bilondi, 2013). The industrial effluents discharged in river might be from chemicals probably from road construction sites, and textiles manufacturing units. The industrial pollution constitutes a major share in the river pollution assessment showed by (Alaqarbeh et *al.*, 2024; Chan et *al.*, 2023; Errich et *al.*, 2024; Grimm et *al.*, 2024). Therefore, the corrective actions for the industrial waste treatment to be taken into consideration before discharge into rivers by every industry and the concerned government authorities to play down the further deterioration of the water quality.

Conclusion

The results of this study showed the strong organic pollution in Ouémé rive in low-water period and the high-water period. The site of Gotin (R1), site of control, present the acceptable pollution index while the sites (R2 to R6) present a very low pollution index because these sites are around of road construction. Nitrite, Phosphate, Ammonium, Chemical Oxygen Demand and Biochemical Oxygen Demand were the parameters that most influenced the level of pollution and this pollution is either slow-biodegradable or non-biodegradable this confirm that the origin of that pollution is not domestic but industrial. The results showed the contribution of road construction around this river to organic pollution, and this pollution is much more pronounced during rainfall due to urban runoff of substances contained in tools used during road construction. Hence the urgent need to put in place effective strategies to reduce organic and inorganic loads in order to ensure the sustainable use of these resources and services.

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