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Physicochemical Characterization, Trace Metal Contamination, and Assessment of Organic Pollution in a Tropical Urban Stream: Case of the Bitshaku-Tshaku River (Kinshasa, DR Congo)

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Abstract

This study aimed to assess the water quality of the Bitshaku-Tshaku River, an urban watercourse located in Kinshasa (Democratic Republic of the Congo), through the analysis of physico-chemical parameters, trace metal elements, and the Organic Pollution Index (OPI). The results showed that water temperature ranges between 27.3 and 29.2 °C, while conductivity and turbidity indicated high mineralization and a significant load of suspended matter. Low dissolved oxygen concentrations (≈ 2.27 mg/L), combined with high values of Biological Oxygen Demand (BOD_5 ≈ 42 mg/L) and Chemical Oxygen Demand (COD ≈ 59 mg/L), revealed substantial organic pollution. High nutrient concentrations (NO_3^- and PO_4^{3-}) reflect excessive enrichment of the environment. Trace metal analysis highlighted notable contamination by lead, cadmium, nickel, and copper. The Organic Pollution Index (OPI ≈ 2.5) indicated overall poor water quality with strong organic pollution. Principal Component Analysis (PCA) revealed that parameter variability is dominated by a gradient of nutrient and mineral pollution of anthropogenic origin. These results demonstrate that the Bitshaku-Tshaku River is heavily impacted by human activities, requiring urgent management and restoration measures to preserve the quality of this water resource.

Keywords: Water quality; Pysicocemical parameters, Heavy metals; Urban stream; Bitshaku-Tshaku river; Kinshasa

1. Introduction

Continental aquatic ecosystems play a fundamental role in maintaining ecological balance and meeting human water needs. However, in rapidly expanding urban areas, these systems are subjected to increasing anthropogenic pressures, including domestic wastewater discharges, industrial effluents, and urban runoff, all of which contribute to the degradation of surface water quality (Meybeck & Helmer, 1989; Walsh *et al.*, 2005). In African cities, where urbanization

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is often unplanned and sanitation infrastructure is inadequate, urban watercourses frequently become direct recipients of multiple pollutants, affecting both their ecological functioning and their use by local populations (UNEP, 2016).

Water quality assessment traditionally relies on the analysis of physico-chemical parameters, which help characterize trophic status, mineralization levels, and the presence of pollutants. Indicators such as Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), nitrogen and phosphorus nutrients, and dissolved oxygen are widely used to diagnose levels of organic pollution and the degree of degradation of aquatic environments (Chapman, 1996; Wetzel, 2001). In addition, the Organic Pollution Index (OPI) provides a synthetic tool that integrates several chemical parameters (notably NH_4^+, NO_2^-, BOD_5, and dissolved O_2) to classify water bodies according to their degree of organic pollution (Leclercq & Maquet, 1987).

Furthermore, contamination of aquatic environments by trace metal elements (TMEs) represents a major environmental issue in urban settings. Metals such as lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), and iron (Fe) are introduced into hydrosystems through various anthropogenic sources, including industrial activities, road traffic, solid waste, and runoff (Förstner & Wittmann, 2012; Tchounwou *et al.,* 2012). These elements are toxic, persistent, and bioaccumulative, thus posing risks to aquatic organisms and human health (Jaishankar *et al*., 2014).

In tropical urban hydrosystems, the combination of organic pollution and metal contamination generates synergistic effects that profoundly alter water quality and associated ecological functions. The joint characterization of physico-chemical parameters, TMEs, and the OPI index therefore provides a comprehensive and relevant environmental diagnosis for sustainable water resource management (Simeonov *et al.,* 2003).

In the Democratic Republic of the Congo, particularly in the city of Kinshasa, urban watercourses face intense anthropogenic pressure linked to rapid population growth and inadequate sanitation systems. The Bitshaku-Tshaku River, which flows through the municipalities of Kinshasa, Barumbu, and Gombe, is a typical example of these highly degraded hydrosystems, receiving continuous inputs of domestic wastewater, industrial effluents, and urban runoff.

In this context, the present study aims to characterize the physico-chemical quality, assess trace metal contamination, and determine the level of organic pollution using the OPI index in the Bitshaku-Tshaku River. More specifically, the objectives are to: (i) analyze the physico-chemical parameters of the water, (ii) quantify heavy metal concentrations, and (iii) evaluate the degree of organic pollution in order to provide scientific insights useful for the management and rehabilitation of this urban watercourse

2. Study Area

The Bitshaku-Tshaku River originally functions as an urban wastewater collector and only resembles a natural watercourse at its mouth, where it discharges into the Congo River. It originates at the intersection of Croix-Rouge and Marché avenues, in the Kinshasa municipality, near the Stade du 24 Novembre, where it is mainly fed by a shallow groundwater table.

With an approximate length of 3 km, the river successively flows through the municipalities of Kinshasa, Barumbu, and Gombe, draining domestic wastewater and stormwater from these highly urbanized areas. Its course begins in the Kinshasa municipality and follows a path roughly parallel to Kilosa Avenue. It then crosses the intersection of Bokassa and Kilosa avenues before entering the Barumbu municipality. From Itaga Avenue onward, its course turns northeastward before joining the Congo River at the former ONATRA shipyard facilities in Ndolo, after flowing underground beneath part of the industrial zone of the Gombe municipality.

The Bitshaku-Tshaku River receives inputs from two main tributaries: the Bakongo stream, which originates south of Kabambare Avenue and joins the river after crossing Luambo-Makiadi Avenue (formerly Bokassa), and the Itaga stream, which runs along the avenue of the same name before merging downstream. In addition, it collects water from several stormwater drainage networks, notably those along Marais, Plateau, and Bokassa avenues, reinforcing its role as an urban collector.

From a morphological perspective, the river has a low longitudinal slope of approximately 2%, which favors the accumulation of sediments and pollutants. It is fully lined with masonry along its entire course and has a trapezoidal cross-section with 45° sloped banks. Its dimensions increase from upstream to downstream, reaching in its final section a width of approximately 6 m at the surface and a depth of 2.3 m, allowing for an estimated discharge of about 50 m^3/s.

This study was conducted in the city-province of Kinshasa, specifically in its northeastern part, within the municipalities of Kinshasa, Barumbu, and Gombe, which constitute the main areas crossed by the Bitshaku-Tshaku River. These zones, characterized by high population density and intense urbanization, exert significant pressure on the ecological quality of this hydrosystem.

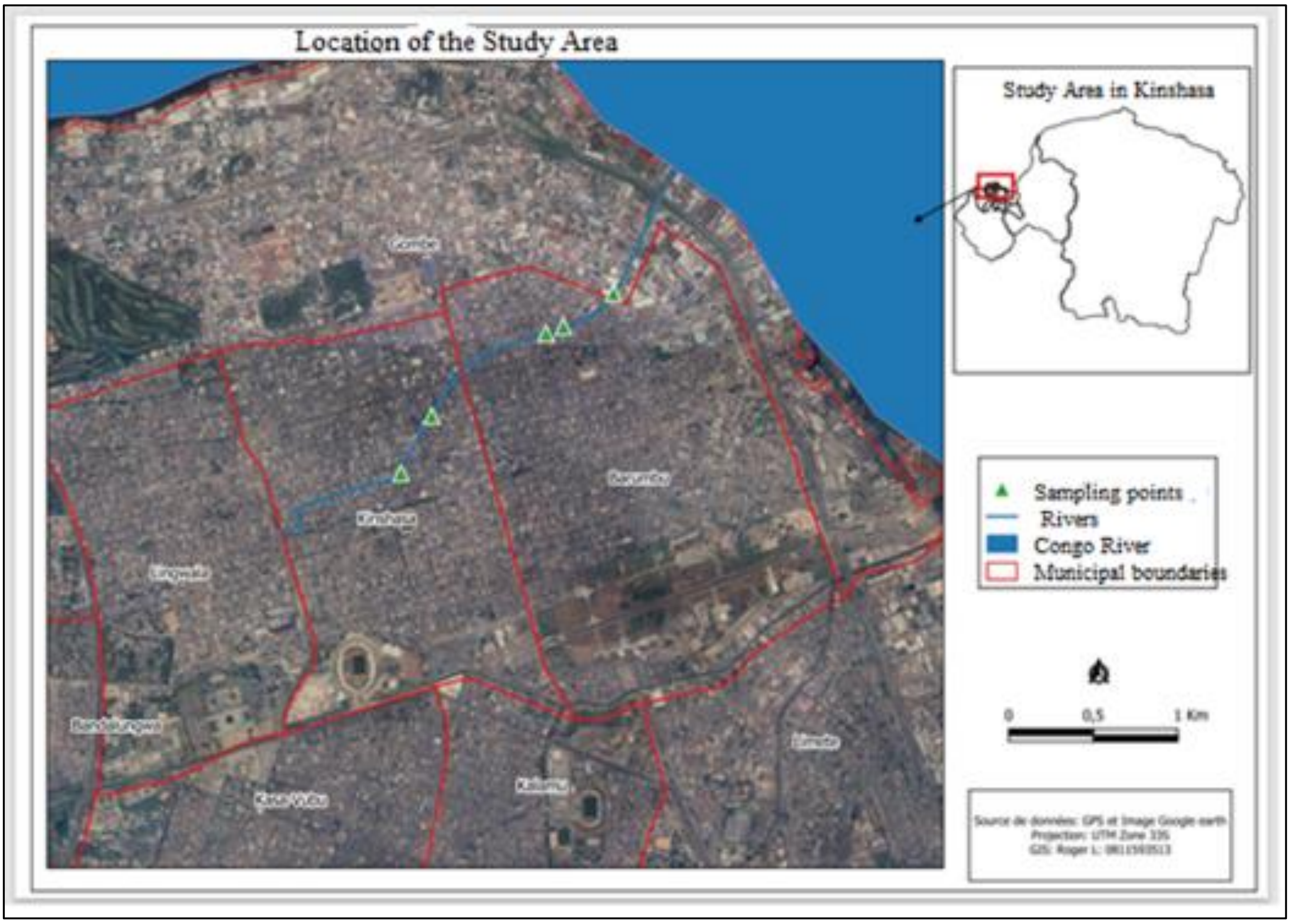

Figure 1 Location of the Bitshaku-Tshaku River and sampling stations

3. Methods

3.1. Physico-chemical characteristics of hydrosystems

3.1.1. Physical parameters

Four physical parameters of the Bitshaku-Tshaku River water were measured *in situ* at each sampling station: water temperature (°C), electrical conductivity at 20°C (µS/cm), turbidity (expressed in Nephelometric Turbidity Units, NTU), and hydrogen potential (pH).

These parameters were measured using a portable multiparameter probe (Hanna Instruments HI 9829), previously calibrated according to the manufacturer's recommendations. *In situ* measurements were preferred to minimize physicochemical alterations that could occur during sample transport.

3.1.2. Chemical parameters

Chemical parameter analyses were carried out at the laboratory of the Commissariat Général à l'Énergie Atomique (CGEA/CREN-K) using water samples collected in the field and preserved under appropriate conditions (clean bottles, transport in a temperature-controlled cooler).

The concentrations of major ions and nutrients were determined using a HACH DR/2400 spectrophotometer, following standardized colorimetric methods. The analyzed parameters included: calcium (Ca^{2+}, mg/L), chlorides (Cl^{-}, mg/L), ammonium (NH_4^{+}, mg/L), nitrites (NO_2^{-}, mg/L), nitrates (NO_3^{-}, mg/L), orthophosphates (PO_4^{3-}, mg/L), and sulfates (SO_4^{2-}, mg/L).

Prior to analysis, water samples were filtered using StonyLab filter papers with a pore size of 50 µm to remove suspended matter that could interfere with measurements. Specific reagents for each parameter were then added according to the manufacturer's protocols, and appropriate wavelengths were selected from the pre-programmed settings of the HACH spectrophotometer.

Biological Oxygen Demand over five days (BOD_5, mg/L) was determined using the standard incubation method in a thermostatic chamber for five days at 20°C, in the absence of light and air. Chemical Oxygen Demand (COD, mg/L) was evaluated using corresponding standardized methods.

Dissolved oxygen measurements used for BOD_5 calculation were performed using a YSI ProODO oximeter, ensuring high accuracy in oxygen concentration readings.

3.2. Trace metal element (TME) analysis

Heavy metal concentrations (Pb, Cd, Ni, Fe, Zn, and Cu) were determined after acid digestion of samples according to standard methods (APHA, 2017). Analysis was conducted using spectrophotometry (or atomic absorption spectrometry, depending on availability), allowing quantification of concentrations in mg/L. The results were compared with international water quality standards (WHO, USEPA) to assess the level of metal contamination.

3.3. Calculation of the Organic Pollution Index (OPI)

The Organic Pollution Index (OPI) was used to assess the degree of organic pollution in the waters of the Bitshaku-Tshaku River. This index is based on four main parameters: ammonium (NH_4^{+}), nitrites (NO_2^{-}), Biological Oxygen Demand (BOD_5), and dissolved oxygen (O_2). Each parameter is assigned to a quality class generally ranging from 1 (very high pollution) to 5 (low pollution), according to thresholds defined by Leclercq and Maquet (1987). The OPI is calculated as the average of the classes assigned to the four parameters:

$OPI=\frac{C_{NH_4}+C_{NO_2}+C_{DBO_5}+C_{CO_2}}{4}$ where Ci represents the quality class associated with each parameter.

Table 1 Interpretation of the Organic Pollution Index

OPI value	Water quality	Pollution level
4.6 – 5.0	Very good	Low
4.0 – 4.5	Good	Low to moderate
3.0 – 3.9	Moderate	Moderate
2.0 – 2.9	Poor	High
1.0 – 1.9	Very poor	Very high

3.4. Statistical analysis

Data were processed using PAST software version 4.03. The non-parametric Kruskal–Wallis test was used to compare variations in physico-chemical parameters between stations, with a significance threshold set at $p < 0.05$.

Principal Component Analysis (PCA) was performed using a data matrix comprising the physico-chemical parameters measured at the different stations. Data were standardized beforehand to eliminate the effect of unit differences. The first two axes explain a significant proportion of the total variance, allowing identification of the main environmental gradients and potential sources of pollution.

4. Results

4.1. Physical parameters of the water of the Bitshaku-Tshaku River

Table 2 shows the variations of the physical parameters of the water of the Bitshaku-Tshaku River during the 2025 rainy season.

Table 2 Physical parameters of the water of the Bitshaku-Tshaku River during the 2025 rainy season

Paramètres	Stations						Mean
	1	2	3	4	5	6	
Temp (°C)	28.1	28.5	29.2	28	27.6	27.3	28.1±0.67
Cond (µS/cm)	658	680	733	687	675	600	672±43.4
Turb (UNT)	51.08	55.32	56.65	50.55	56.26	57.28	54.5±2.95
pH	6.89	6.75	6.67	6.82	7.02	7.5	6.94±0.3

Table 2 presents the variations of the physical parameters of the water of the Bitshaku-Tshaku River during the 2025 rainy season. Water temperature ranged from 27.3 °C (station 6) to 29.2 °C (station 3), with a mean value of 28.1 ± 0.67 °C, indicating relatively homogeneous thermal conditions typical of tropical hydrosystems.

Electrical conductivity varied from 600 µS/cm (station 6) to 733 µS/cm (station 3), with a mean of 672 ± 43.4 µS/cm, indicating relatively high mineralization of the water. Turbidity ranged from 50.55 NTU (station 4) to 57.28 NTU (station 6), with a mean of 54.5 ± 2.95 NTU, reflecting a high load of suspended matter during the study period.

The pH ranged between 6.67 (station 3) and 7.5 (station 6), with a mean of 6.94 ± 0.3, indicating generally neutral to slightly alkaline waters.

Statistical analysis using the non-parametric Kruskal–Wallis test revealed no significant differences among stations for all studied physical parameters ($H = 0.12$; $p > 0.05$), suggesting relative spatial homogeneity of the physical characteristics of this hydrosystem during the study period.

4.2. Chemical parameters of the water of the Bitshaku-Tshaku River

The variations of the chemical parameters during the 2025 rainy season are presented in Table 3.

Table 3 Chemical parameters of the water of the Bitshaku-Tshaku River during the 2025 rainy season

Parameters (mg/L)	Stations						Mean
	1	2	3	4	5	6	
Oxydis	2.17	2.32	2.26	2.31	2.38	2.19	2.27±0.08
DBO5	38.84	41.63	43.47	40.56	42.21	46.12	42.1±2.5
DCO	57.2	60.45	62.01	56.43	58.89	63.4	59.7±2.73
NH_4^+	0.1234	0.11515	0.1127	0.1257	0.1615	0.1442	0.13±0.02
NO_2^-	0.052	0.0585	0.061	0.065	0.0716	0.059	0.06±0.01
NO_3^-	394.2	289.48	386.07	368.13	297.55	384.05	353±47.1
PO_4^{-3}	57.3	51.02	22.9	21.83	45.04	50.22	41.4±15.2
SO_4^{-2}	16.7	24.49	12.4	12.8	18.94	21.76	17.8±4.84
Ca^{2+}	4.196	3.84	3.763	3.674	4.824	4.196	4.08±0.43

Table 3 shows the variations of chemical parameters during the 2025–2026 rainy season. Dissolved oxygen ranged from 2.17 mg/L (station 1) to 2.38 mg/L (station 5), with a mean of 2.27 ± 0.08 mg/L, indicating generally hypoxic conditions throughout the hydrosystem.

Biochemical Oxygen Demand over five days (BOD_5) ranged from 38.84 mg/L to 46.12 mg/L, with a mean of 42.1 ± 2.5 mg/L, indicating a high load of biodegradable organic matter. Similarly, Chemical Oxygen Demand (COD) ranged from 56.43 mg/L to 63.4 mg/L, with a mean of 59.7 ± 2.73 mg/L, reflecting a high total organic load.

Nitrogen forms were also elevated. Ammonium (NH_4^+) ranged from 0.1127 to 0.1615 mg/L (mean: 0.13 ± 0.02 mg/L), while nitrites (NO_2^-) ranged from 0.052 to 0.0716 mg/L (mean: 0.06 ± 0.01 mg/L). Nitrates (NO_3^-) showed particularly high values (289.48–394.2 mg/L; mean: 353 ± 47.1 mg/L), suggesting strong anthropogenic pollution.

Orthophosphates (PO_4^{3-}) ranged from 21.83 to 57.3 mg/L (mean: 41.4 ± 15.2 mg/L), indicating significant nutrient enrichment likely to promote eutrophication. Sulfates ranged from 12.4 to 24.49 mg/L (mean: 17.8 ± 4.84 mg/L).

Calcium ranged from 3.674 to 4.824 mg/L (mean: 4.08 ± 0.43 mg/L), indicating a moderate contribution to overall mineralization.

Kruskal–Wallis test results showed no significant differences among stations (H = 0.22; $p > 0.05$), indicating spatial homogeneity of chemical conditions along the river.

4.3. Trace Metal Elements in the water of the Bitshaku-Tshaku River

Table 4 Trace metal elements (TME) during the 2025 rainy season

TME (mg/L)	Stations						Mean
	1	2	3	4	5	6	
Lead	0.81	0.119	0.761	0.709	0.339	0.805	0.59±0.29
Cadmium	0.375	0.364	0.179	0.168	0.373	0.387	0.31±0.1
Nickel	0.48	0.37	0.072	0.69	0.43	0.44	0.41±0.2
Iron	19.2	37	0.392	3.92	3.71	9.01	12.2±13.8
Zinc	0.03	0.017	0.012	0.014	0.017	0.03	0.02±0.01
Copper	0.09	0.2	18	1.68	1.2	0.59	3.63±7.07

The results show significant contamination by several trace metals. Lead exhibited high concentrations (mean: 0.59 ± 0.29 mg/L). Cadmium showed relatively uniform distribution. Nickel displayed strong spatial variability, indicating localized inputs.

Iron showed extremely high variability, with a peak of 37 mg/L. Zinc remained low and relatively homogeneous. Copper exhibited extreme variability, with a maximum of 18 mg/L, suggesting point-source pollution.

Overall, these findings highlight significant metal contamination with spatial heterogeneity linked to anthropogenic inputs.

4.4. Evaluation of the Organic Pollution Index (OPI)

Table 5 Evaluation of the Organic Pollution Index (OPI) of the Bitshaku-Tshaku River during the rainy season 2025

Station	O_2	BOD_5	NH_4^+	NO_2^-	OPI	Quality	Interpretation
1	2	1	4	3	2.5	Poor	Strong pollution
2	2	1	4	3	2.5	Poor	Strong pollution
3	2	1	4	3	2.5	Poor	Strong pollution
4	2	1	4	3	2.5	Poor	Strong pollution
5	2	1	4	3	2.5	Poor	Strong pollution
6	2	1	4	3	2.5	Poor	Strong pollution

The values of the Organic Pollution Index (OPI) calculated for all stations of the Bitshaku-Tshaku River are identical and amount to 2.5, indicating an overall poor water quality and strong organic pollution along the entire studied stretch.

This homogeneity in OPI values reflects a diffuse and continuous anthropogenic pressure along the watercourse, likely related to domestic wastewater discharges and uncontrolled urban inputs. The low concentrations of dissolved oxygen associated with high BOD_5 values are the main factors responsible for this degradation.

4.5. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) performed on the physicochemical parameters of the Bitshaku-Tshaku River highlighted the main environmental gradients structuring water quality. The first two axes alone explain 92.37% of the total variance, with axis 1 (PC1) accounting for 82.76% and axis 2 (PC2) for 9.61%.

The strong contribution of axis 1 indicates that data variability is dominated by a single principal gradient, reflecting a major environmental factor influencing water quality.

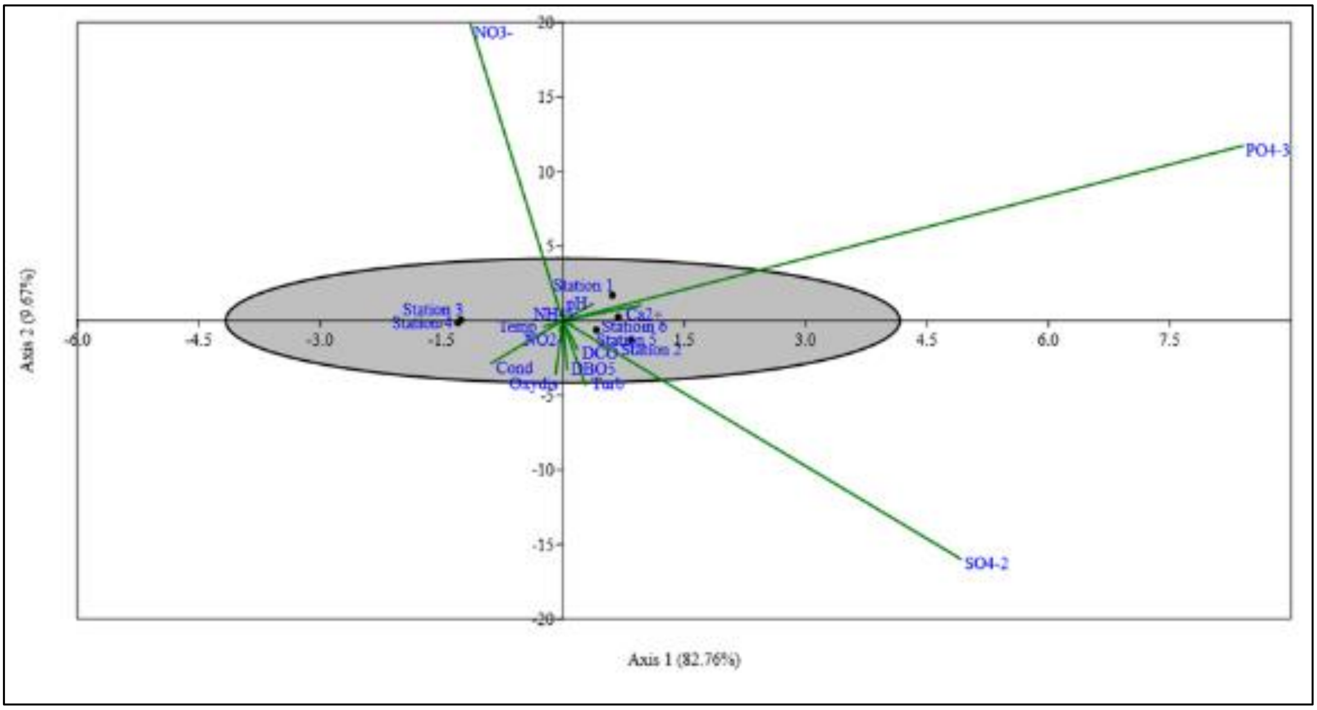

Figure 2 Principal Component Analysis (PCA) of the physicochemical parameters of the Bitshaku-Tshaku River during the 2025 rainy season

Axis 1 is strongly structured by orthophosphates (r = +0.8484), sulfates (r = +0.49628), nitrates (r = −0.11518), and conductivity (r = −0.089336). This axis mainly represents a gradient of pollution by nutrients and dissolved salts. The strong positive contribution of phosphates indicates a marked influence of domestic discharges (detergents, wastewater). Sulfates also contribute to this gradient, suggesting inputs of urban or industrial origin. The negative contribution of nitrates may indicate a different distribution of this parameter, possibly linked to transformation processes (nitrification/denitrification).

Axis 2 is mainly influenced by nitrates (r = +0.68498), phosphates (r = +0.40351), sulfates (r = −0.54928), turbidity (r = −0.14685), and dissolved oxygen (r = −0.12227). This axis highlights a secondary gradient opposing, on the one hand, nutrient-rich waters (NO_3^-, PO_4^{3-}) and, on the other hand, waters with higher particulate loads (turbidity) and lower oxygen concentrations.

5. Discussion

The Bitshaku-Tshaku River exhibits physico-chemical characteristics typical of highly anthropized tropical urban hydrosystems. The relatively stable temperature (27.3–29.2 °C) reflects tropical climatic conditions and is consistent with observations reported for tropical streams (Allan & Castillo, 2007; Kamb, 2018; Sisa *et al.,* 2022). The low dissolved oxygen concentrations (≈2.27 mg/L), combined with high BOD_5 (≈42 mg/L) and COD (≈59 mg/L) values, indicate a high organic load and increased oxygen consumption due to biological degradation processes (Chapman, 1996). These values are characteristic of environments receiving untreated domestic discharges (Metcalf & Eddy, 2003; Sisa *et al*., 2022).

Very high nutrient concentrations, particularly nitrates and orthophosphates, indicate excessive nutrient enrichment likely to promote eutrophication processes (Wetzel, 2001). These inputs are generally associated with domestic wastewater and urban runoff (Meybeck *et al*., 1996). The absence of significant differences between sampling stations confirms diffuse pollution, typical of urban systems where pollution sources are multiple and continuous (Allan, 2004).

The high concentrations of lead, cadmium, and nickel observed in this study indicate significant metal contamination. These levels exceed recommended thresholds for surface waters and are generally associated with anthropogenic activities such as industrial discharges, urban traffic, and infrastructure corrosion (WHO, 2017). The high variability of iron and copper suggests the presence of point sources of pollution, likely linked to local industrial activities and port facilities (Förstner & Wittmann, 2012). Similar observations have been reported in other African urban rivers (Nyenje *et al.,* 2010).

The observed multi-metal contamination constitutes a major ecotoxicological risk for aquatic organisms, particularly due to the bioaccumulative and synergistic effects of these metals (Rainbow, 2002). The values of the Organic Pollution Index (OPI) indicate poor water quality (OPI ≈ 2.5), confirming high organic pollution. This situation is consistent with high BOD_5 values and low dissolved oxygen concentrations, reflecting an overload of biodegradable organic matter (Leclercq & Maquet, 1987). The observed organic pollution is mainly linked to untreated domestic wastewater discharges, a common phenomenon in developing cities (UNEP, 2016). The low spatial variation of the OPI further confirms the diffuse nature of this pollution.

Principal Component Analysis (PCA) revealed a primary gradient of nutrient pollution dominated by orthophosphates and sulfates, reflecting the influence of urban anthropogenic activities (Shrestha & Kazama, 2007). The second axis reflects a secondary gradient related to nutrient dynamics and organic degradation processes. The low contribution of organic parameters (BOD_5, NH_4^+) indicates pollution homogeneity, confirming the results obtained from the OPI and statistical analyses.

Overall, the results highlight an advanced degradation of water quality, characterized by organic pollution, eutrophication, and metal contamination. These conditions lead to reduced biodiversity and favor pollution-tolerant species (Bonada *et al.,* 2006). Furthermore, the presence of heavy metals at high concentrations represents a risk to human health, particularly in cases of prolonged exposure (WHO, 2017).

6. Conclusion

This study on the Bitshaku-Tshaku River enabled an integrated assessment of water quality through the analysis of physico-chemical parameters, trace metals, and the Organic Pollution Index (OPI). The results reveal advanced degradation of water quality, characterized by low dissolved oxygen concentrations and high BOD_5 and COD values, indicating a high load of biodegradable organic matter. Elevated nutrient concentrations, particularly nitrates and orthophosphates, reflect excessive enrichment of the system, potentially leading to eutrophication.

Trace metal analysis shows significant contamination by several heavy metals, particularly lead, cadmium, nickel, and copper, with concentrations exceeding recommended thresholds for surface waters. This contamination reflects the influence of anthropogenic activities, including domestic discharges, urban effluents, and industrial activities along the river.

Assessment of organic pollution using the OPI indicates generally poor water quality across all stations, with strong and relatively homogeneous organic pollution. PCA results confirm that parameter variability is dominated by a nutrient pollution gradient of anthropogenic origin, associated with diffuse contamination.

Thus, the Bitshaku-Tshaku River appears to be a highly degraded hydrosystem subjected to continuous anthropogenic pressure. This situation not only compromises the ecological balance of the ecosystem but also poses a potential risk to the health of nearby populations.

In light of these findings, it is essential to implement urgent environmental management measures, including: the establishment of wastewater treatment systems, control of domestic and industrial discharges, public awareness on water resource protection, and regular monitoring of water quality.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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