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Assessment of Physicochemical Characteristics and Heavy Metal Contamination in River Kaduna, Nigeria: Implications for Water Quality and Ecosystem Health

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ABSTRACT
Freshwater systems in developing regions are increasingly threatened by anthropogenic pollution, with significant consequences for ecosystem health and human use. This study assessed the physicochemical properties and heavy metal contamination of River Kaduna, Nigeria, to evaluate its water quality status. Water samples were collected from upstream (control) and downstream (polluted) locations and analyzed using standard procedures. Results indicated substantial deterioration in water quality at polluted sites, characterized by reduced dissolved oxygen (3.1 mg/L), elevated biological oxygen demand (6.9 mg/L), and high turbidity (45 NTU). Nutrient enrichment was evident, with increased nitrate and phosphate concentrations. Heavy metals, particularly lead (0.35 mg/L) and cadmium (0.05 mg/L), exceeded recommended limits. These findings highlight severe anthropogenic influence, posing ecological and public health risks. The study underscores the need for continuous monitoring and regulatory intervention.

Keywords: Water Quality, Heavy Metals, River Kaduna, Physicochemical Parameters, Pollution, Nigeria

INTRODUCTION
Freshwater ecosystems are critical for sustaining biodiversity, supporting human livelihoods, and maintaining ecological balance. However, increasing urbanization, agricultural intensification, and industrial activities have led to widespread degradation of water bodies, particularly in developing countries (Vörösmarty *et al.,* 2021). In Nigeria, rivers serve as primary sources of water for domestic and agricultural purposes, yet they are frequently exposed to untreated effluents and runoff (Ogunfowokan *et al.,* 2021).
Water contamination is a pressing global crisis that threatens human health, ecosystems, and sustainable development. The United Nations' Sustainable Development Goal 6 (SDG 6) aims at ensuring the access to clean water and sanitation by 2030, yet billions lack safe drinking water, contributing to poverty and disease (UN, 2023). Contaminated water is linked to waterborne diseases such as cholera and dysentery, with over 1.5 million deaths annually, primarily in low-income countries (Prüss-Ustün *et al.,* 2021; WHO, 2024). Poor water quality exacerbates poverty by limiting access to safe resources for drinking, agriculture, and industry, particularly in sub-Saharan Africa (Ortiz *et al.,* 2022). Addressing water contamination is critical to achieving global health and environmental sustainability. The scale of water contamination is staggering, with an estimated 2.2 billion people lacking access to safely managed drinking water and 3.6 billion without adequate sanitation (UN, 2023). This crisis disproportionately affects marginalized communities in developing nations, where infrastructure deficiencies and industrial pollution exacerbate the problem (Bartram & Cairncross, 2022).
Physicochemical parameters such as pH, dissolved oxygen (DO), and nutrient concentrations provide essential insights into water quality and ecosystem functioning (Wetzel, 2001). In addition, heavy metals are of major concern due to their persistence, bioaccumulation, and toxicity, even at low concentrations (Landrigan *et al.,* 2023).
Despite the ecological importance of periphytic algae as primary producers and reliable indicators of water quality, limited information is available on the effects of chlorpyrifos contamination on their growth and diversity in Nigerian freshwater ecosystems, particularly River Kaduna. Furthermore, few studies have simultaneously examined the combined influence of pesticide exposure, physicochemical characteristics, and heavy metal contamination on periphytic algal communities in this river, creating a significant knowledge gap in understanding the ecological consequences of pesticide pollution (Ren, 2021). Addressing this gap is essential for providing scientific evidence that can support effective water quality monitoring, pollution control, and sustainable management of freshwater ecosystems (Zhang et al., 2019; Wu et al., 2021). Therefore, this study was designed to evaluate selected physicochemical parameters and heavy metal concentrations in River Kaduna and to determine the toxic effects of chlorpyrifos on the growth and diversity of periphytic algae. It was hypothesized that chlorpyrifos contamination would adversely affect the physicochemical quality of the water and significantly reduce the growth and diversity of periphytic algae in the aquatic ecosystem (Asselborn et al., 2015; Serra et al., 2021).

MATERIALS AND METHODS
Sample Collection
Water sample was collected once at Yakowa Bridge (coordinates: approximately 10.5264°N, 7.4388°E), River Kaduna, located at Chikun Local Government Area, Kaduna State, Nigeria.
All analyses were conducted following standard methods recommended for water quality assessment. (APHA, 2017). Samples were transported to the Botanical laboratory in Biological Science Department, Kaduna State University.

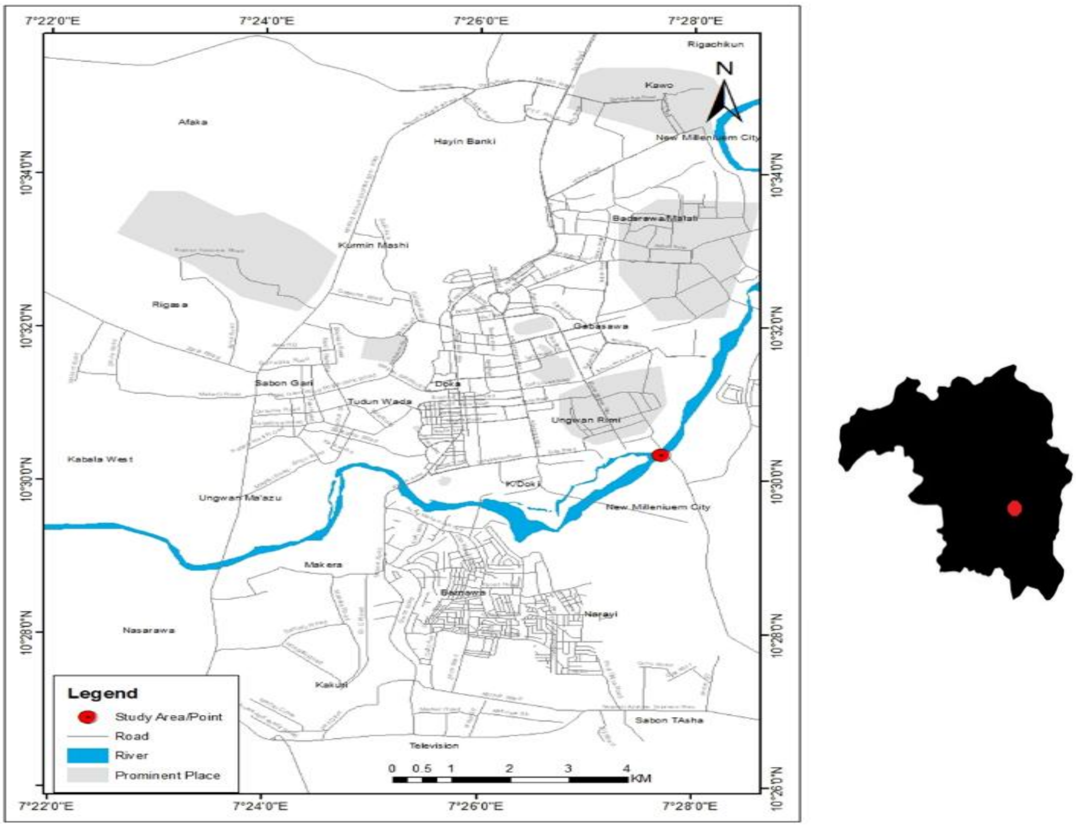

Figure 1: Map of the Study Area Showing Sampling Point Yakowa Bridge, Kaduna State. (10.5264°N, 7.4388°E)

Sampling Design

Sampling was conducted at two locations along River Kaduna: an upstream control site with minimal anthropogenic disturbance and a downstream site subjected to intense human activities. These sites were selected to represent relatively unpolluted and polluted conditions, respectively. Water samples were collected in sterile containers and preserved according to standard procedures (APHA, 2017).

Physicochemical and Heavy Metal Analysis

Samples intended for physicochemical analysis were stored in an ice chest and transported immediately to the laboratory for analysis. Physicochemical parameters were measured to assess water quality and its influence on periphytic growth, following standard methods (APHA, 2017). The parameters included:

pH

Measured in situ using a portable pH meter (Hanna HI98129), calibrated daily with standard buffers.

Dissolved Oxygen (DO)

Determined using a YSI Pro20 DO meter, with measurements taken at mid-depth to ensure accuracy.

Temperature

Monitored continuously using a digital thermometer, with hourly readings logged via a data logger (HOBO UX100, accuracy ±0.2°C).

Nutrients

Nitrate, phosphate, and ammonium concentrations were quantified using Hach colorimetric test kits and a spectrophotometer (Hach DR3900, wavelength 400–700 nm). Calibration curves were prepared using standard solutions ($R^2 > 0.99$). Concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) were analyzed using inductively coupled plasma-optical emission spectrometry (ICP-OES, PerkinElmer Optima 8000) after acid digestion, following EPA Method of 2007 and (EPA, 2021). Detection limits were 0.01 mg/L for Pb, 0.002 mg/L for Cd, and 0.005 mg/L for Cr. Measurements were taken weekly, and quality control included duplicate analyses and blanks to ensure precision (<20 mg/L relative standard deviation). Results were compared to WHO and EPA water quality standards to assess environmental safety (WHO, 2024).

The analysis of the selected heavy metal was carried out using BUK 235 Atomic Absorption Spectrophotometer (AAS). The elements determined by this method were lead (Pb), zinc (Zn), cadmium (Cd), Chromium (Cr) and copper (Cu).

The water samples were collected and digested by transferring 100cm^3 into a flask and 5cm^3 of freshly prepared nitric acid (HNO_3), 15cm^3 of concentrated tetraoxosulphate (vi) acid (H_2SO_4) and 0.3cm perchloric acid ($HClO_4$) were added. The solution was stirred and heated on a hot plate for 2 hours at 100^o C to dry and digest until a dense white fume appeared which was then ingested for 15minutes, allowed to cool and filtered into a 100cm^3 volumetric flask. The filtrate was diluted to the mark with distilled water (Ogbozige *et al.,* 2017 and Sadiq *et al.,* 2022). The digested sample solution was placed in a 100cm^3 volumetric flask and made up to 100cm^3, three concentrations of standard solution of a particular metal to be analyzed were selected accordingly for calibrations; blank solution was selected and adjusted to zero. Each standard solution was aspirated into flame, the concentration of each metal in water sample were determined at specific determinant wavelength by using appropriate hollow cathode lamp. (AOAC, 2015).

Data Analysis

Descriptive statistics were used to compare variations between sampling sites. Statistical analyses were performed using the General Linear Model (GLM) to evaluate the effects of chlorpyrifos treatments on physicochemical parameters, heavy metal concentrations, and periphytic algal growth. Results were evaluated against WHO (2017) standards. Physicochemical parameters were correlated with periphytic metrics using Pearson's correlation analysis. Heavy metal concentrations were compared to WHO/EPA standards to assess environmental safety.

RESULTS AND DISCUSSION

The tables present the physicochemical characteristics and heavy metal concentrations of water samples collected from the control and polluted sections of River Kaduna, compared with the World Health Organization (WHO) permissible limits for water quality.

The results show variations in heavy metal concentrations across treatments and the control. Zinc (Zn) and copper (Cu) levels were relatively low and remained within WHO permissible limits, indicating no major contamination risk from these metals. In contrast, lead (Pb) and cadmium (Cd) concentrations exceeded WHO standards across all treatments and the control, indicating significant contamination. Chromium (Cr) levels were also consistently high and far above the WHO limit, suggesting severe pollution in the system. The findings indicate that while Zn and Cu are not of major concern, Pb, Cd, and Cr represent serious heavy metal pollution in the study area, likely linked to anthropogenic activities such as agricultural runoff, industrial discharge, and urban waste inputs. The results show that temperature, pH, EC, and TDS remained relatively stable and within WHO permissible limits across all treatments. However, dissolved oxygen (DO) showed a marked decline in some treatments, especially at 100 mg/L, indicating oxygen stress in the system.

Nitrate and phosphate levels varied across treatments, with some values exceeding recommended limits, suggesting nutrient enrichment and potential eutrophication risk. Overall, while most basic water quality parameters remained acceptable, reduced DO and elevated nutrients indicate ecological stress associated with chlorpyrifos exposure.

Physicochemical Parameters

Table 1 shows that Zinc (Zn) concentration ranged from 0.0073 ± 0.01 mg/L to 0.1563 ± 0.01 mg/L across treatments. The highest Zn value was recorded at 40 mg/L (0.1563 ± 0.01 mg/L), while the lowest occurred at 140 mg/L (0.0073 ± 0.01 mg/L). The control recorded a Zn concentration of 0.0307 ± 0.01 mg/L.

Copper (Cu) concentrations varied between 0.0143 ± 0.01 mg/L and 0.0437 ± 0.04 mg/L. The highest Cu concentration was observed in the control (0.0437 ± 0.04 mg/L), while the lowest value was recorded at 100 mg/L (0.0143 ± 0.01 mg/L). The WHO guideline value for Cu was 2.0 mg/L.

Lead (Pb) concentration ranged from 0.0600 ± 0.01 mg/L to 0.2090 ± 0.04 mg/L. The highest Pb value was recorded at 20 mg/L (0.2090 ± 0.04 mg/L), while the lowest was observed in the control and at 100 mg/L (0.0600 ± 0.01 mg/L). The WHO permissible limit for Pb is 0.01 mg/L.

Cadmium (Cd) concentrations ranged between 0.0067 ± 0.00 mg/L and 0.0110 ± 0.00 mg/L. The highest Cd concentration occurred in the control (0.0110 ± 0.00 mg/L), while the lowest value was recorded at 140 mg/L (0.0067 ± 0.00 mg/L). The WHO guideline value for Cd is 0.003 mg/L.

Chromium (Cr) concentrations ranged from 2.6057 ± 0.03 mg/L to 2.8100 ± 0.08 mg/L. The highest Cr concentration was recorded in the control (2.8100 ± 0.08 mg/L), while the lowest value occurred at 140 mg/L (2.6057 ± 0.03 mg/L). The WHO standard for Cr is 0.05 mg/L.

Table 1: Physicochemical Parameters

Treatment	Zn (mg/L)	Cu (mg/L)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
20 mg/L	0.0130±0.004c	0.0300±0.02a	0.2090±0.04a	0.0083±0.00a	2.7743±0.016ab
40 mg/L	0.1563±0.01a	0.0387±0.0a	0.0707±0.1a	0.0087±0.00a	2.7163±0.043b
100 mg/L	-0.0020±0.00d	0.0143±0.0a	0.0600±0.0a	0.0097±0.006a	2.7433±0.170ab
140 mg/L	0.0073±0.01cd	0.0213±0.0a	0.0463±0.0a	0.0067±0.00a	2.6507±0.034b
Control	0.0307±0.01b	0.0437±0.0a	0.0640±0.0a	0.0110±0.00a	2.8100±0.08a
WHO Standard	<3.0mg/L	2.0 mg/L	0.01mg/L	0.003 mg/L	0.05 mg/L

Heavy Metal Concentrations

Table 2 shows water temperature ranged from 23.10 ± 0.10 °C to 23.31 ± 0.15 °C. The highest temperature was recorded at 140 mg/L (23.31 ± 0.15 °C), while the lowest occurred at 20 mg/L (23.10 ± 0.10 °C). pH values ranged between 7.75 ± 0.06 and 7.92 ± 0.03. The highest pH was recorded in the control (7.92 ± 0.03), while the lowest occurred at 20 mg/L (7.75 ± 0.06). Electrical conductivity (EC) ranged from 288.00 ± 2.65 µS/cm to 313.33 ± 2.52 µS/cm. The highest EC value was recorded at 100 mg/L (313.33 ± 2.52 µS/cm), while the lowest occurred in the control (288.00 ± 2.65 µS/cm).

Dissolved oxygen (DO) concentration ranged from 0.90 ± 0.10 mg/L to 5.47 ± 0.25 mg/L. The highest DO was recorded at 140 mg/L (5.47 ± 0.25 mg/L), while the lowest value occurred at 100 mg/L (0.90 ± 0.10 mg/L).

Total dissolved solids (TDS) ranged between 130.33 ± 1.58 mg/L and 154.33 ± 0.04 mg/L. The highest TDS was recorded at 100 mg/L (154.33 ± 0.04 mg/L), while the lowest occurred at 20 mg/L (130.33 ± 1.58 mg/L). Nitrate-nitrogen (NO_3–N) concentrations ranged from 26.00 ± 1.00 mg/L to 30.00 ± 1.00 mg/L. The highest NO_3–N value was recorded at 40 mg/L (30.00 ± 1.00 mg/L), while the lowest occurred in the control (26.00 ± 1.00 mg/L).

Phosphate-phosphorus (PO_4–P) concentrations ranged from 0.0830 ± 0.00 mg/L to 0.6000 ± 0.02 mg/L. The highest PO_4–P concentration was recorded at 140 mg/L (0.6000 ± 0.02 mg/L), while the lowest occurred at 100 mg/L (0.0830 ± 0.00 mg/L.

Table 2: Heavy Metal Concentrations

Treatment	TEMP (°C)	pH	EC (µS/cm)	DO (mg/L)	TDS (mg/L)	NO3-N (mg/L)	PO-P (mg/L)
20 mg/L	23.10±0.10a	7.75±0.06^b	301.33±3.51b	3.27±0.21^c	150.33±1.53b	27.00±1.00b	0.81±0.02c
40 mg/L	23.17±0.15a	$7.84±0.04^{ab}$	$283.00±2.00^{c}$	$2.97±0.15^{c}$	$142.33±2.52^{c}$	$30.00±1.0^{a}$	$1.95±0.0^{b}$
100 mg/L	$23.20±0.10^{a}$	$7.84±0.02^{ab}$	$313.33±2.52^{a}$	$0.90±0.10^{d}$	$154.33±4.04^{a}$	$29.00±1.0^{a}$	$0.83±0.0^{c}$
140 mg/L	$23.13±0.15^{a}$	$7.90±0.05^{a}$	$305.67±4.16^{ab}$	$5.47±0.25^{a}$	$153.33±2.08^{ab}$	$17.23±0.25^{c}$	$0.60±0.02^{d}$
Control	$23.03±0.06^{a}$	$7.92±0.03^{a}$	$288.00±2.65^{c}$	$4.30±0.20^{b}$	$141.33±1.53^{c}$	$26.00±1.00^{b}$	$2.30±0.10^{a}$
WHO Standard	25°c	6.5-8.5	<1000mg/L	5.0mg/L	<600mg/L	50mg/L	-

Discussion

The heavy metal profile indicates that River Kaduna is contaminated with lead, cadmium, and chromium, suggesting considerable anthropogenic influence on water quality. The elevated concentrations of these metals above the recommended WHO guideline values indicate potential ecological and public health risks associated with industrial effluents, agricultural runoff, and other human activities along the river catchment (WHO, 2017). Similar observations were reported by Ogunfowokan et al. (2021), who attributed heavy metal contamination in Nigerian rivers to industrial discharges and agricultural activities. Likewise, Igwe and Onyekwere (2022) associated elevated chromium concentrations in Nigerian freshwater systems with tannery effluents and other industrial wastes.

In contrast, zinc and copper concentrations remained within the permissible limits recommended by the World Health Organization, indicating that contamination in the study area was selective rather than widespread across all trace metals. Similar trends have been reported by Akan et al. (2020), who observed elevated concentrations of lead and chromium but comparatively low levels of zinc and copper in urban rivers in northern Nigeria. The unusually low zinc concentration observed in one treatment may be associated with the adsorption and bioaccumulation of metals by periphytic algae, a process that has been reported to reduce dissolved metal concentrations in aquatic environments (Serra et al., 2021).

The physicochemical characteristics further suggest that chlorpyrifos exposure altered water quality conditions. Although the pH remained within the acceptable range for freshwater ecosystems, dissolved oxygen declined markedly in some treatments, indicating increased biological stress and reduced photosynthetic activity of aquatic primary producers. Similar reductions in dissolved oxygen following pesticide exposure have been reported by Wu et al. (2021), who demonstrated that organophosphate pesticides suppress algal photosynthesis and microbial respiration. The relatively acceptable levels of total dissolved solids and nitrate indicate that ionic composition remained within recommended limits, whereas elevated phosphate concentrations suggest nutrient enrichment that could increase the risk of eutrophication. Comparable findings were reported by Ogunfowokan et al. (2021), who linked nutrient enrichment in Nigerian rivers to agricultural runoff and domestic waste discharges.

The observed relationship between physicochemical parameters and periphytic algal composition agrees with Mukoro et al. (2026), who reported that nutrient enrichment and other anthropogenic influences altered periphyton distribution and community structure in Nwaniba River.

CONCLUSION

This study successfully evaluated the physicochemical characteristics and heavy metal concentrations of River Kaduna in relation to international water quality standards. The findings revealed noticeable variations between the control and polluted sites, indicating significant deterioration of water quality in the polluted section of the river. Physicochemical parameters such as dissolved oxygen, biological oxygen demand, turbidity, nitrate, and phosphate showed levels associated with pollution stress and ecological disturbance.

The study also determined the concentrations of selected heavy metals, where lead and cadmium exceeded the permissible limits recommended by the World Health Organization (WHO). These elevated concentrations suggest contamination from anthropogenic activities such as agricultural runoff, industrial discharge, and urban waste disposal. Although copper and zinc remained within acceptable limits, their increased levels in the polluted site further indicate environmental pressure on the aquatic ecosystem.

Comparison of the obtained results with international water quality standards confirmed that parts of River Kaduna are polluted and may pose risks to aquatic organisms and human populations depending on the river for domestic and economic activities. Therefore, continuous monitoring, proper waste management, and stricter environmental regulations are necessary to reduce pollution and improve the ecological health of River Kaduna.

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