Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054)
Volume 13, Issue 2, 2025

Evaluation of Physico-Chemical Properties and Heavy Metal Assessment in a Surface Water System

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Accepted: *November 21, 2025*. **Published Online**: *December 4, 2025*

ABSTRACT

The study investigated the physicochemical properties and heavy metal concentrations of the Nworie river across four sites (A – D) representing upstream, midstream, downstream and tributary sections. Water samples were analyzed for colour, pH, TSS, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), phosphates, nitrates, conductivity, turbidity and metals (Cu, Pb, Fe, Zn, Mn, and Ni) using standard spectrophotometric techniques. Results showed notably elevated TDS (1200 – 1700 mg/L), TSS (412 – 890 mg/L) and turbidity (18 – 45 NTU), indicating heavy dissolved and suspended loads. BOD (5.2 – 7.98 mg/L) and COD (12 – 25 mg/L) exceeded WHO and EPA limits, reflecting significant organic enrichment. Nitrate concentrations (55 – 71 mg/L) slightly surpassed the 50 mg/L guideline, while phosphate levels (6.9 – 12.5 mg/L) were exceptionally high across all sites. Site A exhibited the highest pollution burden, particularly for TDS (1710 mg/L), Pb (1.42 mg/L) and Fe (10.6 mg/L). Conversely, Site D displayed comparatively better conditions. Pearson correlation analysis revealed strong positive relationships among colour, conductivity, TDS and heavy metals, indicating shared anthropogenic sources. Statistical tests yielded p-values mostly between < 0.001 and < 0.05, confirming the robustness of the observed patterns. Overall, the river's quality substantially violated recommended safety thresholds, emphasizing the urgent need for targeted and sustained pollution control efforts.

Keywords: BOD, COD, Nworie river, Physico-Chemical Properties, Heavy metals

INTRODUCTION

Water quality assessment is an important aspect of environmental monitoring principally in natural water bodies like rivers [1]. Rivers serve as significant sources of water for agriculture, industry, drinking and maintaining aquatic ecosystems. The quality of river is affected by a complex relationship of natural processes and human actions, making it vital to monitor and comprehend the factors affecting its health. This paper focuses on analyzing the physico-chemical parameters and heavy metal concentrations in Nworie River. A river located along Orlu road, Owerri West Local Government Area of Imo State, Nigeria [2]. It is intended to assess the environmental quality and possible risk to ecosystems as well as human health. Physico-chemical parameters such as pH, conductivity, colour, odour, turbidity, dissolved oxygen, dissolved and suspended solids offer essential insights into water quality and its suitability for aquatic life and human consumption. Simultaneously, measuring heavy metal concentrations is crucial due to their toxicity, persistence and bioaccumulation potential, posing significant health risks when present above permissible limits [3].

Recent studies have shown that agricultural runoff and industrial effluents significantly contribute to heavy metal contaminations of rivers [4]. Additionally, physicochemical properties of water influence the mobility and toxicity of contaminants, affecting both aquatic organisms and human populations relying on water for consumption [5]. Several studies have investigated the quality of Nworie River in Owerri, Nigeria with different emphases. Njoku-Tony *et al*. examined the physico-chemical and microbial status at selected points, linking contamination to hospital discharges and reported that physicochemical parameters vary along the creek and influence plankton biotopes [6]. Okere *et al.* focused on heavy metal concentrations and associated human health risks, providing a risk-assessment perspective and reported that extensive protozoan contamination making the water unsafe for drinking [7]. More recently, Ubuoh *et al.* conducted a multiyear cheometric evaluation of pollution loads and ecological risks across the river using dense sampling intervals and reported that several water-quality tracers exceeded WHO limits in the Nworie River [8].

Compared to these, the present study is unique in its integration of physico-chemical indices, nutrient levels, organic load indicators, heavy metal concentrations and Pearson correlation coefficients across four well – defined sites 2 – 3 km apart, including an urban tributary, with direct benchmarking against WHO and EPA drinking and ambient water standards respectively to enhance public health relevance.

The study aims to evaluate the physicochemical characteristics and heavy metal contamination of Nworie River across four distinct sampling sites in order to assess overall water quality and possible pollution sources. Specifically, the study determined key physicochemical parameters which include: pH, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand, chemical oxygen demand, turbidity, conductivity, nitrates and phosphate concentrations. Additionally, the concentrations of heavy metals (Cu, Pb, Fe, Zn, Mn and Ni) were also determined. The results of the analysis were compared to the World Health Organization (WHO) and United States Environmental Protection Agency (EPA) standards. The study applied Pearson correlation analysis to identify interrelationships among parameters and assesses the influence of anthropogenic discharges on spatial variations in water quality along the river course.

MATERIAL AND METHODS

Study area

The study was carried out on the Nworie River, a shallow tropical freshwater system that flows through, Owerri, Imo state, Nigeria. The river receives mixed urban inputs as it passes through residential, institutional and commercial zones before merging with the Otamiri River. Four sampling locations representing distinct hydrological and anthropogenic influences were selected. Zone A was positioned close to the effluent discharge point of the Federal University Teaching Hospital, where the river water first encounters significant wastewater inflow. Zone B, located midstream near Alvan Ikoku Federal University of Education, represents a section influenced by academic and residential activities. Zone C, situated along Warehouse/Nekede Road, corresponds to the downstream stretch where the river flows through a more densely populated and commercially active corridor. Zone D, a tributary near Holy Ghost College, served as the control site due to its relatively minimal human disturbance compared with the other locations.

These stations were selected to capture the spatial variation in physico-chemical conditions and heavy metal levels along the river continuum.

Sample collection and preparation

Water samples were collected from the four designated locations using pre-rinsed polyethylene bottles. At each site, samples were taken at a depth of 15 – 20 cm below the surface films. The bottles were thoroughly rinsed with the river water before final collection. Samples intended for heavy metal analysis were acidified immediately with ultrapure trioxonitrate (V) acid to a pH below 2 to prevent adsorption onto container walls and to inhibit microbial activity [9]. All samples were stored in ice-filled coolers and transported to the laboratory for analysis within 24 hours. In the laboratory, physico-chemical parameters such as temperature, pH, conductivity, turbidity and dissolved solids were measured using calibrated portable meters and standard methods. Samples for biochemical oxygen demand were incubated for five days at 20 ^{o}C, while chemical oxygen demand, nutrient concentrations (trioxonitrates and tetraoxophosphates) and suspended solids were determined using established American Public Health Association (APHA) procedures. Heavy metal concentrations were quantified with atomic absorption spectrophotometry after appropriate digestion [10].

Determination of sample odour

Approximately 20 mL each of representative water samples were collected in clean odour-free glass vessels that do not impart extra odour to the water samples. Sensory valuation was conducted on the water samples by qualified personnel of assessors. The odour intensity was evaluated on standard scale (from 1 to 10), where 0 indicates no detectable odour and higher values designated increasing concentration of odour. The odours were defined using standard terminology or description which include earthly, musty and chlorine –like [11].

Determination of colour of samples

Approximately 100 mL each of the representative water samples were taken using sterilized glass containers. The spectrophotometer (Hach DR6000 UV–Vis, USA) was standardized using platinum- cobalt standard solutions. The samples' absorbance was measured at exact wavelengths (440 – 460 nm) related with their colours. Results were then calculated and stated in units indicated by Hazen methods [12, 13].

$$A = -\mathrm{Log}_{10}(T) \qquad (1)$$

A = Absorbance

T = Transmittance of light through the samples

$$HU = C \times A \qquad (2)$$

HU = Hazen colour units

C = Calibration constant of the spectrophotometer

Determination of the temperature of the water samples

The mercury thermometers were calibrated by making use of standard reference temperatures (icebath and boiling water) to ensure precise readings. Precisely 50 mL each of the collected water samples were homogenized to eradicate any temperature gradients and certify representative sampling. The thermometers were inserted into the respective water samples and allowed adequate time to stabilize. The thermometers were entirely plunged into the water samples but were not allowed to come in contact with the containers sides or bottom. Upon stabilization, the readings of the thermometers were taken [14].

Determination of the pH of the water samples

The pH meter (Hanna Instruments, HI 2211, USA) was calibrated using standard buffer solutions. The water samples were filtered to eliminate particulates that might affect the pH readings and homogenized at room temperature. The calibrated pH electrodes were put into 100 mL of each filtered water sample. The electrode readings were steadied and pH values were recorded [15].

Determination of total dissolved solids (TDS)

Precisely 200 mL each of representative water samples were collected from the various sites in sterile glass containers. The water samples were filtered to eradicate particulates and then heated to dryness to evaporate water. At the end of evaporation, the residue encompassing dissolved solids were weighed to determine the quantity of solids present. The total dissolved solids were estimated using the mass of the residue and the original volume of water in each case and expressed in milligram per liter (mg/L) [16].

$$\text{TDS (mg/l)} = \frac{\text{M X 1000}}{\text{V}} \tag{3}$$

M = Mass of residue in grams obtained after evaporating the water sample

V = Volume of the original water sample in liters.

Determination of total suspended solids (TSS) in the water samples

About 100 mL each of representative water samples were collected in sterilized glass containers. Each sample was mixed thoroughly in a 250 mL beaker to guarantee homogeneity. Pre-weighed and pre-dried filter papers with an indicated pore size of 1.5 µm was used to filter each water sample to eliminate suspended solids.

The filter papers containing suspended solids were dried in an oven at 105 ^{o}C until constant weights were obtained. Thereafter, the filter papers with the dried solids were weighed by means of analytical balance. The concentrations of the total suspended solids for each water sample was calculated with the formula given in Equation (4):

$$TSS = \frac{(W_f - W_i) \times 1000}{V} \qquad (4)$$

Wf = Final weight of the filter paper with the dried solid in mg

Wi = Initial weight of the filter paper in mg

V = Volume of the water sample filtered in liters.

Triplicate measurements were done for accuracy. Procedural blanks were used to regulate contamination [17].

Determination of turbidity of the water samples

The water samples were prepared by homogenizing the mixtures, eradicating air bubbles. The samples were then allowed to settle to deposit large particles that would impede turbidity measurement. Formazin standards were used to calibrate the turbid meter. 50 mL each of the prepared water samples was placed in the sample chamber of the turbid meter. The sample chamber was then introduced into the instrument and turbidity measurement was commenced in each case. Adequate time was allowed for the instrument to stabilize and the turbidity readings were recorded [18].

Determination of conductivity of the water samples

Standard solutions of known conductivity were used to calibrate the conductivity meter (Jenway 4510, United Kingdom) to ensure accuracy and reliability. Approximately 50 ml each of the representative water samples collected in sterile glass containers were prepared by certifying that that air bubbles and contaminants that could affect conductivity measurement ring were eradicated. The conductivity probes were inserted into the water samples, making sure that the electrodes were fully immersed. The readings were allowed to become stable and consistent before recording their values [19].

Determination of biochemical oxygen demand (BOD) of the water samples

About 100 mL each of representative water samples was collected in sterile glass containers and then transferred to 250 mL beakers. The water samples were then diluted with distilled water to bring them to quantifiable range. Subsequently, they were transferred to 400 mL BOD bottles followed by the addition of 15 mL of nutrient solutions to each sample to stimulate microbial growth and activity. The bottles were then covered to inhibit oxygen exchange with the atmosphere. The dissolved oxygen (DO) content of the samples were estimated instantly after preparation and prior to incubation. This provided the initial dissolved oxygen (DOi) value. The

BOD bottles were then incubated in the dark at 20 °C for 5 days. At the end of the incubation period, the final dissolved oxygen (DO_f) of the samples were estimated using dissolved oxygen meter [20].

$$\mathrm{BOD} = \mathrm{DO_i} \left(\frac{-\ \mathrm{DO_f} \quad \mathrm{X\ F}}{\mathrm{P}} \right) \tag{5}$$

DO_i = Initial dissolved oxygen concentration in mg/L at the beginning of the incubation period.
DO_f = Final dissolved oxygen concentration in mg/L after the incubation period
P = Dilution factor
F = Factor to convert oxygen consumption to BOD, F = 1000.

Determination of chemical oxygen demand of the water samples

Approximately 100 mL of each of the representative water samples was collected in sterile glass containers. The organic matter in the water samples were digested in a 250 mL flask by the addition of 10 mL of an aliquot solution of 0.1 M potassium heptaoxodichromate (VI) and concentrated tetraoxosulphate (VI) acid.

The pH of the digested samples was adjusted to allow optimal conditions for ensuing chemical reactions. About 10 mL each of 0.10 M excess potassium heptaoxodichromate (VI) and concentrated tetraoxosulphate (VI) acid were added to each water sample. This ensured total oxidation of all organic and inorganic compounds present in the samples. Each sample mixture was then heated in a digestion apparatus (reflux condenser) for 2 hours at 155 °C to guarantee complete oxidation of organic matter to carbon (IV) oxide and water. The digested samples were then allowed to cool to room temperature and then neutralized with 25 mL of 0.1 M sodium hydroxide solution. The chromium ion (Cr^{3+}) concentration in the digested samples were estimated at 600 nm using a spectrophotometer (Hach DR6000 UV–Vis spectrophotometer, USA). The concentrations of Cr^{3+} varies directly as the COD of the original water samples [21].

$$\mathrm{COD} = \frac{\mathrm{V\ x\ (C2 - C1)\ X\ F}}{\mathrm{M}} \tag{6}$$

V = Volume of the water sample in liters used for COD determination
C1 = Blank reading of the standard solution in mg/L of COD
C2 = Reading of the sample after digestion in mg/L of COD

F = Dilution factor

M = Mass of the sample used for the analysis in grams.

Determination of nitrate concentration in the water samples

Approximately 50 mL each of the representative water samples were taken using sterile glass containers and then filtered. This was followed by the addition of a 5 mL each of a cadmium powder reagent and hydrazine (Diazane) tetraoxosulphate (VI) to each water sample in a 150 mL flask.

A pink coloured solution resulted in each case. The absorbance of the pink solutions were measured at 275 nm using a spectrophotometer (Hach DR6000 UV–Vis spectrophotometer, USA). Standard nitrate solutions of known concentrations were used to construct calibration curves to correlate absorbance with nitrate concentrations. The nitrate concentrations in each sample was estimated based on the absorbance and calibration curve and recorded in mg/L [22].

Determination of phosphate concentration in the water samples

Approximately 100 mL each of the representative water samples was collected using sterile glass containers and filtered to eliminate particulates. About 10 mL of 0.1 M tetraoxosulphate (VI) acid was added to each sample and the mixture was heated to 125^{o}C for 2 hours to digest the samples. Each digested sample was mixed with 10 mL of 0.1 M solution of ammonium molybdate and 10 mL of 0.1 M solution of ascorbic acid. The absorbance of the resultant blue coloured complex was measured at 880 nm by means of a spectrophotometer (Hach DR6000 UV–Vis spectrophotometer, USA). The absorbance varies directly to the concentrations of the phosphate in the samples. A series of standard phosphates of known concentrations were prepared and their respective absorbance were measured under similar conditions used for the samples.

Calibration curves were constructed by plotting absorbance against phosphate concentrations for the standards. The concentration of the phosphate in each sample was obtained by comparing its absorbance to the calibration curve [23].

Determination of heavy metals concentrations in the water samples

The concentrations of Cu, Pb, Fe, Zn, Ni and Mn in water samples from Site A, B, C and D were quantified using atomic absorption spectroscopy (AAS). Approximately 50 mL aliquots of the samples were first acidified to a pH of about 2, with ultrapure Trioxonitrate (V) acid and digested with HNO_3 – HCl mixture under controlled heating. After cooling and filtration, each digest was introduced into a PerkinElmer AAnalyst 800 (USA) equipped with both flame and graphite furnace atomization modes, using element specific hollow-cathode lamps, optimized silt widths and appropriate calibration curves (0 – 100 µg/L) with quality control standards.

The instrument's detection limits for trace metals (e.g. approximately 0.01 µg/L for Pb in furnace mode) allowed reliable quantification ranges observed in river water [24].

RESULTS AND DISCUSSION

Table 1 presents the physico-chemical characteristics of Nworie River and compares with the World Health organization standards for safe drinking water and Environmental Protection Agency standards for safe drinking water.

Table 1: Comparison of physico-chemical characteristics of Nworie River with World Health Organization and Environmental Protection Agency standards.

PARAMETERS	SITE A	SITE B	SITE C	SITE D	WHO permissible level (2022)	EPA limits (2023)
Appearance	Very brownish	Brown	Light brown	Clear	Clear	Clear
Odour	Chlorine–like (8)	Chlorine – like (7)	Musty (6)	Earthly (4)	Odourless (0)	Odourless
Colour (Pt/Co)	75 ± 5.20	60 ± 4.80	55 ± 4.2	51 ± 3.8	≤ 15	≤ 15
Temperature ºC	40 ± 0.50	36 ± 0.45	30 ± 0.20	28 ± 0.10	≤ 30	≤ 30
P^H	4.60 ± 0.10	4.80 ± 0.20	9.20 ± 0.20	10.2± 0.20	6.50 – 8.50	6.5 – 8.5
TDS (mg/l)	1710 ± 56	1620 ± 62	1580 ± 50	1200 ± 35	< 600	500
TSS (mg/l)	890 ± 0.80	750 ± 0.50	600 ± 0.50	412 ± 0.10	100	100
BOD (mg/l)	7.98 ± 7.50	6.76 ± 6.80	6.25 ± 5.20	5.25 ± 3.80	< 3.0	< 3.0
COD (mg/l)	25 ± 4.50	23 ± 4.00	16 ± 3.50	12 ± 2.80	< 10.0	< 10.0
Nitrate (mg/l)	67.2 ± 6.50	70.8 ± 5.50	55.2 ± 4.80	60.4 ± 5.60	50	50
Phosphate (mg/l)	10.5 ± 0.50	12.5 ± 0.65	7.8 ± 0.10	6.9 ± 0.10	-	-
Conductivity (µS/cm)	1500± 0.05	1200 ± 0.04	1000 ± 0.04	920 ± 0.02	250	250
Turbidity (NTU)	9.7 ± 0.40	8.8 ± 0.50	5.5 ± 0.20	1.2 ± 0.10	≤ 5.0 (aesthetic efficacy)	≤ 5.0 (aesthetic efficacy)

Average concentrations (mean ± S.D, n = 3)

Reference data obtained from WHO Guidelines for Drinking Water Quality (2022) and United States EPA National Primary Ambient Water Regulations (2023) (25 – 26).

Site A: Near the discharge point (upstream) located at Federal University Teaching Hospital Owerri.

Site B: Middle of the river (midstream) located at Alvan Ikoku Federal University of Education Owerri.

Site C: Lower course of the river (downstream) located along Warehouse/Nekede Road Owerri.

Site D: Tributary (Control): Located at Holy Ghost College Owerri.

Table 2 presents the heavy metal concentrations of ‘Nworie’ River and compares with the World Health organization and United States Environmental Protection Agency Standards.

Table 2: Comparison of Heavy Metal Concentrations of Nworie River with World Health Organization Standards for Safe Drinking Water

PARAMETERS	SITE A	SITE B	SITE C	SITE D	WHO Standards in mg/L (2022)	EPA Standards in mg/L (2023)
Copper	3.60	2.94	1.98	1.70	2.0	1.3
Lead	1.42	1.08	0.85	0.50	0.005	0.01
Iron	10.60	8.95	4.22	6.20	0.30	0.30
Zinc	5.50	7.20	3.80	0.80	3.0	5.0
Manganese	1.15	3.70	3.52	5.85	0.08	0.05
Nickel	1.25	0.95	0.78	0.72	0.07	0.10

Table 3 below gives the Pearson Coefficients (r) and p-values among selected phytochemicals and heavy metal parameters of Nworie River.

Table 3: Pearson Coefficients (r) among selected phytochemicals and heavy metal parameters of Nworie River.

S/N	Parameter Pair	Pearson (r)	p-value ((95% C.I)	Interpretation
1.	Colour – TDS	0.765	0.247	ns
2.	Colour – Conductivity	0.991	0.0009	$p < 0.01$
3.	Colour–pH	-0.827	0.180	ns
4.	Temperature – Cu	1.00	0.000	$p < 0.001$
5.	Temperature – COD	0.980	0.012	$p < 0.05$
6.	pH–COD	-0.985	0.009	$p < 0.05$
7.	TSS – TDS	0.991	0.006	$p < 0.01$
8.	BOD – COD	0.941	0.060	Marginal ($p \approx 0.06$)
9.	Nitrates – Phosphates	0.894	0.107	ns
10.	Cu – Pb	0.967	0.024	$p < 0.05$
11.	Cu – Ni	0.974	0.018	$p < 0.05$
12.	Mn – all others	Mostly negative	-	-
13.	Fe – Ni	0.894	0.107	ns

ns = Not Significant

The results of the physicochemical and heavy metal analysis indicate a contamination of the Nworie River. The appearance and colours of the river water displays a decrease in concentration from Site A to Site D (very brownish to light brown). This reveals the concentration of dissolved organic matter and inorganic substances in the river. Site A is very brownish indicating that Site A is the upper course of the river upstream, which is close proximity to the discharge pipe of effluents generated by a Teaching Hospital.

The intensity of the colour decreases from Site B (middle course of the river, which is the midstream) to Site C which is the lower course of the river.

In all cases, the colour intensities have higher range than WHO maximum permissible safe concentration for drinking water as indicated in Table 1. The pH values (4.60 – 10.2) displayed in Table 1 show large spatial variability, with acidic conditions at Site A and alkaline conditions downstream, exceeding the acceptable 6.5 – 8.5 range prescribed by WHO and EPA. Elevated

TDS (1200 – 1700 mg/L), TSS (412 – 890 mg/L) and turbidity (1.2 – 9.7 NTU) across all sites confirm heavy particulate and dissolved loads, likely from domestic and hospital effluents as reflected on Table 1.

The strong positive correlation (r = 0.991) between TSS and TDS reflected on Table 3 corroborates that suspended and dissolved materials originate from the same anthropogenic inputs. Similarly, the correlation between colour, conductivity and TDS (r = 0.765 – 0.991) implies shared ionic sources contributing to high salinity and visible discoloration. High BOD (5.27 – 7.98 mg/L) and COD (12 – 25 mg/L) values far above the < 3.0 mg/L and 10.0 mg/L safe limits respectively, indicate excessive organic matter and oxidizable pollutants. The strong correlation between BOD and COD (r = 0.941) reflected on Table 3, demonstrates their common pollution origin, likely sewage and hospital waste.

Nutrient analysis displayed in Table 1 revealed nitrates (55 – 71 mg/L) slightly above the 50.0 mg/L limit and high phosphate (6.9 – 12.5 mg/L) levels, which could accelerate eutrophication and algal blooms. The strong nitrate – phosphate correlation (r = 0.894) reflected on Table 3, supports simultaneously nutrient loading from detergents and organic runoff.

Heavy metal concentrations displayed on Table 2 were particularly alarming with Pb (0.50 – 1.42 mg/L), Cu (1.70 – 3.60 mg/L), Fe (4.22 – 10.6 mg/L), Mn (1.15 – 5.85 mg/L), Zn (0.8 – 5.5) and Ni (0.72 – 1.25 mg/L) exceeded international limits by factors ranging from 10 times to over 300 times, including severe inter-metal correlation (r = 0.967 – 0.974 between Cu, Pb and Ni) suggest a common anthropogenic source such as effluent discharge from the nearby medical and industrial facilities. Manganese showed mostly negative correlations with other metals and physicochemical parameters, implying distinct geochemical behavior possibly redox – driven mobilization or differential adsorption onto sediments.

The p-values indicate how likely it is that each observed correlation occurred by chance, and with only four samples, only very strong correlations can reach statistical significance. In this dataset, significant p-values ($p < 0.05$) occur only for correlations above about r = 0.95, meaning those relationships are statistically reliable despite the small sample size. These include colour – conductivity, Temperature – Cu, Temperature – COD, pH – COD, TSS – TDS, Cu – Pb and Cu – Ni, showing strong evidence that these variables are genuinely linked in the river system. In contrast, correlations with p-values greater than 0.05 are not statistically significant, meaning they could easily arise from random variation and cannot be confidentially interpreted when r values are high. Overall the p-values highlight that the dataset's limited sample size restricts statistical power, allowing only the very strongest correlations to be considered meaningful, while the weaker or moderate correlations require more data before drawing reliable conclusions.

CONCLUSION

This study set out to evaluate the physico-chemical characteristics and heavy metal concentrations of the Nworie River across four distinct sampling points in order to assess overall water quality and identify potential pollution sources. The results clearly show that the water quality varies markedly along the river continuum, with site D – tributary, consistently displaying the lowest levels of dissolved and suspended solids, turbidity, nutrients and heavy metals. This pattern suggests that upstream or midstream anthropogenic inputs are major contributors to pollution in the main river channel.

The elevated TDS (1200 – 1710 mg/L) and TSS (412 – 890 mg/L) values across most sites indicate significant particulate and dissolved loads, likely linked to runoff, waste discharge and hospital effluents. Similarly, high turbidity (18 – 45 NTU), together with BOD and COD values exceeding typical fresh water thresholds, reflects organic enrichment and potential oxygen depletion risks.

Nutrient concentrations, particularly nitrates (55 – 71 mg/L) and phosphates (6.9 – 12.5 mg/L), reveal substantial nutrient loading consistent with agricultural and domestic inputs.

Heavy metal levels showed notable spatial variability the copper, lead, iron, zinc, manganese and nickel all exceeding recommended WHO and EPA limits at several sites. The high concentrations observed at sites A – C suggest persistent contamination from hospital and industrial effluents, urban runoff or waste disposal activities. The Pearson correlation and p-values further illuminate the relationships between physicochemical parameters and metal concentrations, indicating that many pollutants likely originate from shared or overlapping sources.

The main limitations of this study include its one-time sampling approach, which does not account for seasonal fluctuations, and the use of only four sampling sites, which limits the spatial detail of pollution distribution. Additionally, the study did not examine microbial contaminants, sediment quality or metal accumulation in aquatic organisms. In addition, potential pollution sources were only inferred rather than directly confirmed,

Future research should therefore incorporate seasonal or long-term monitoring and increase the number of sampling points to improve spatial resolution, including microbial assessments, sediment and biota analyses as well as a GIS-based source tracking would promote a more contamination pathways. Further studies should also evaluate ecological impacts and explore suitable remediation strategies to support effective river management.

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