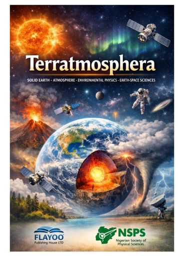
Produced and hosted by FLAYOO Publishing House LTD on behalf of the Nigerian Society of Physical Sciences (NSPS)

Terratmosphera

Solid Earth • Atmosphere • Environment • Space Sciences

https://flayoophl.com/journals/index.php/terratmosphera



Assessment of some physicochemical parameters and heavy metals in River Benue at Wurukum abattoir, Makurdi Metropolis, Benue State, Nigeria

Mathew Olaleke Aremu[a], Benjamin Zobada Musa[a,b,*], Catherine Mnena Aba[a], Bilyamin Ishaq[a], Jude Chinedu Onwuka[a], Augustine Uche Abel[a], Francis Busuyi Iyiola[c]

[a]*Department of Chemistry, Federal University of Lafia, P.M.B. 146, Lafia, Nasarawa State, Nigeria*
[b]*Department of Chemistry, Federal University of Agriculture, Zuru, PMB 28, Kebbi State, Nigeria*
[c]*Department of Science Education, University of Nigeria, Nsukka, Enugu State, Nigeria*

ARTICLE INFO

Article history:
Received: 27 May 2026
Received in revised form: 22 June 2026
Accepted: 23 June 2026
Available online: 14 July 2026

Keywords: River Benue, Abattoir effluent, Physicochemical parameters, Heavy metals
DOI:10.61298/terratmosphera.2026.1.1.384

ABSTRACT

This study assessed the impact of abattoir effluents on the water quality of River Benue around the Wurukum Abattoir, Makurdi, Benue State, Nigeria, using selected physicochemical parameters and heavy metal concentrations as pollution indicators. Water samples were collected from four sampling stations and analysed using standard methods recommended by the American Public Health Association (APHA) and the Association of Official Analytical Chemists (AOAC). Temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), total hardness (TH), and total acidity (TA) were measured, while heavy metals were analysed by atomic absorption spectrophotometry (AAS). Temperature (28.97–29.30 °C), pH (6.3–6.8), and EC (30–90 μS/cm) were within acceptable ranges for freshwater systems. Total hardness ranged from 158 to 180 mg/L, indicating hard-water conditions. DO concentrations were low (0.94–2.16 mg/L), indicating limited oxygen availability. BOD ranged from 2.2 to 79 mg/L, with the highest value at the abattoir discharge point, suggesting substantial organic loading from untreated effluent. Chromium (0.327–0.532 mg/L), lead (1.885–2.716 mg/L), and manganese (0.075–1.772 mg/L) exceeded permissible drinking-water limits, while cadmium was not detected. The findings indicate that abattoir effluents and other anthropogenic activities contribute to water-quality deterioration in River Benue.

1. INTRODUCTION

Water pollution is a pressing environmental issue that poses a threat to human health, the environment, and the socio-economic development of society around the world. Rapid urbanization, population growth, industrialization, and indiscriminate disposal of wastes have significantly increased environmental pollution in

*Corresponding author: Tel. No.: +234-903-376-1919.
e-mail: benzmusa@gmail.com (Benjamin Zobada Musa)

many developing countries, particularly in sub-Saharan Africa [1, 2]. Polluted water resources continue to be a significant global public health problem, affecting the spread of water-borne diseases, environmental degradation and mortality risks. According to the latest World Health Organization figures, there are still some 2.2 billion people without safely managed drinking water services, and unsafe water, sanitation, and hygiene cause hundreds of thousands of preventable deaths every year, particularly in low- and middle-income countries, where the majority of children reside [3].

The sources of water pollution include both natural and anthropogenic sources. Natural contaminants can come from soil particles, dissolved minerals, decomposing organic matter, and biological processes in the aquatic system. In many developing countries, however, anthropogenic sources such as industrial effluents, agricultural runoff, municipal wastewater and waste discharges, mining, and abattoir operations have now become the primary sources of aquatic contamination [4, 5]. Rapid population growth has also put a strain on freshwater resources, leading to their overexploitation, eutrophication, salinization, and high levels of heavy metals in aquatic ecosystems [2].

Water pollution may occur through point and non-point sources. Point source pollution is pollution from a known discharge point, such as an industrial effluent pipe, municipal drainage system, or sewage channel, while non-point-source pollution is pollution originating from a non-point source, such as agricultural runoff or urban surface wash-off [6]. Water pollution can result from many industrial and agricultural activities, including the discharge of heavy metals, hydrocarbons, pesticides, nutrients, suspended solids and pathogenic microorganisms into water bodies [7, 8]. Agricultural runoff containing fertilizers, pesticides, animal wastes, and abattoir residues has been widely reported as a significant source of river pollution in developing countries [1].

Abattoir activities are among the prominent anthropogenic sources of aquatic pollution and have received significant environmental concern due to the large volume of untreated effluents released into nearby water bodies. Abattoir effluents contain high concentrations of organic loads, suspended solids, fat, blood, grease, hair, animal tissues, intestinal content, pathogenic microorganisms, and toxic heavy metals, which can pose a serious threat to water quality and public health [9–11]. In addition, the practice of abattoir operations in many developing countries is generally conducted in unhygienic conditions, without adequate wastewater treatment systems and environmental laws. It is, therefore, not unusual to have untreated effluents pumped directly into nearby streams and rivers, resulting in a high level of environmental pollution [12].

Previous studies have shown that the activities of abattoirs may adversely influence the quality of soils, groundwater, and surface water due to the introduction of pathogenic contaminants and heavy metals into the environment [13]. Environmental concern is given to heavy metals (lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), zinc (Zn)) due to their non-biodegradable properties, bioaccumulation potential, toxicity, and persistence. They can be bioaccumulated in aquatic organisms, plants, animals, and humans within the food chain, leading to significant ecological and public health hazards [2, 5]. Polluted water and contaminated forage from polluted environments may lead to bioaccumulation of these toxic metals in animal tissues and milk, and aquatic organisms living in polluted rivers may also act as vectors for heavy metal exposure in humans.

The environmental impacts of an abattoir's waste production are high. Research has indicated that slaughterhouse activity produces significant amounts of solid and liquid wastes such as blood, manure, paunch contents, bones, fats, and wastewater with high organic and inorganic contents [1, 12]. Large quantities of undigested feed materials, cellulose fibres, protein, nitrogenous compounds, bacteria and organic residues are present in livestock manure and rumen contents and can lead to high levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and microbial contamination of receiving waters. Decomposition and degradation of such wastes in aquatic systems can cause undesirable effects including depletion of oxygen, foul odor, eutrophication and deterioration of aquatic biodiversity [2, 14].

Also, poor animal carcass hygiene and handling have been linked with animal carcass contamination with microorganisms and animal-derived food poisoning in abattoirs. Meat products and water bodies can become contaminated with pathogenic microorganisms like *Escherichia coli*, *Salmonella spp.*, and other enteric bacteria via contact with animal feces and untreated wastewater [15]. This contamination poses a risk to the health of communities relying on contaminated water for drinking, household purposes, agriculture and fishing.

The investigations carried out on the environmental monitoring of the rivers and groundwater bodies in Nigeria indicate that the anthropogenic input to the contamination of heavy metals has been on the rise. According to Ololade *et al.* [2], elevated levels of Cd, Cr, Cu, Ni, and Pb were detected in rivers of the south-western region of Nigeria, and industrial discharge, urban wastewater, and agricultural run-off were attributed to be the major sources of pollution. The study also found that children were at a special risk of carcinogenic and non-carcinogenic health effects from exposure to contaminated water over time. Likewise, Yahaya *et al.* [5] found that the levels of Pb, Ni, and Cd in groundwater sources in Lagos State, Nigeria, were not in compliance, and chronic exposure to contaminated water resources poses a long-term toxicological threat.

Bakare-Abidola *et al.* [1] analyzed physicochemical parameters and heavy metal pollution in abattoir wastewater in Lagos State, Nigeria, and found higher concentrations of Pb, Mn, and Cd than the recommended environmental limits. The authors highlighted the importance of robust wastewater treatment and monitoring of the environment to minimize pollution to the surrounding aquatic ecosystems. Similarly, Amaechi-Onyerimma *et al.* [4], noted high levels of contamination in groundwater resources in Port Harcourt from infiltration of untreated abattoir effluents in the surrounding soils and aquifers. Also, Ref. [13] found that the heavy metal content of agricultural soils and food crops planted with abattoir wastewater samples was significantly higher than in those without such irrigation, suggesting the possibility of carcinogenic and non-carcinogenic health risks to consumers in Delta state, Nigeria.

Although there have been concerns about the environmental effects of abattoir activities in Nigeria, information on the pollution status of the River Benue around the Wurukum abattoir in Makurdi is limited. Hence, this study was aimed at assessing the physicochemical parameters of the River Benue in the vicinity of Wurukum Abattoir and the concentration of the heavy metals and the possible public health and environmental impact of using the river water for domestic and agricultural activities.

2. MATERIALS AND METHODS

2.1. RESEARCH DESIGN

This study employed a purposive non-probability sampling design. This is because it was necessary to select sampling locations that can best represent the effect of abattoir activities on the River Benue. Four sampling points were strategically located around the Wurukum Abattoir along the River Benue and designated as Station A, Station B, Station C and Station D.

- Station A: Was upstream of the abattoir discharge point, near the New Bridge, and was therefore used as the control station, as there was little direct contamination from abattoir activity.
- Station B: Located at the point where abattoir wastes are directly discharged into the drainage channel adjacent to the river. The abattoir has significant wash-down effluents at this station.
- Station C: Located at the confluence of the drainage channel into the main River Benue, which carries the effluent from the abattoir.
- Station D: Located downstream on the main River Benue near the Old Bridge, approximately 500 m away from Station C, to assess the extent of pollutant dispersion along the river course.

2.2. STUDY AREA

The River Benue rises in the Cameroons highlands and flows into Nigeria to the west. It is the second largest river in Nigeria, almost 1488 km in length, and has a significant alluvial flood plain on both sides. The river flows through the capital, Makurdi of Benue State to join the River Niger at Lokoja in Kogi State of Nigeria. Makurdi lies between latitude 7°44′N and longitude 8°32′E within the Guinea Savannah ecological zone [16]. Wurukum Abattoir is situated along the bank of the River Benue in the southern part of Makurdi metropolis. Untreated abattoir effluents are discharged into the river at this place, including the blood, animal tissues, fats, and the wastewater generated during slaughtering and cleaning. These wastes are often washed straight into the river channel. The continuous discharge is a great threat to the physicochemical and bacteriological quality of river water.

2.3. CHEMICALS AND REAGENTS

All chemicals and reagents used in this study were analytical grade to achieve the accuracy and reliability of analytical results. The reagents used included nitric acid (HNO_3), hydrochloric acid (HCl), silver nitrate ($AgNO_3$), and distilled water, sodium chloride (NaCl), ammonium chloride (NH_4Cl), potassium chromate (K_2CrO_4), ethylenediaminetetraacetic acid (EDTA), methyl orange, and phenolphthalein. These reagents were used for the determination of selected physicochemical parameters and heavy metal content of water samples according to the standard procedures recommended by the Association of Official Analytical Chemists [17] and the American Public Health Association [18].

2.4. SAMPLE COLLECTION AND PRE-TREATMENT

Water samples were collected from the four designated sampling stations along the River Benue around the Wurukum Abattoir. Sampling was carried out in accordance with standard procedures for water quality assessment. At each sampling station, water samples were collected at a depth of approximately 10–15 cm below the water surface using properly labeled acid-washed polyethylene containers to avoid contamination and minimize changes in sample characteristics [18].

The samples were labeled according to their respective sampling stations (A, B, C, and D). For heavy metal determination, the collected water samples were immediately preserved by adding 2 mL of concentrated nitric acid in order to prevent metal precipitation and adsorption onto the walls of the containers [19]. The samples were thereafter stored in an ice chest at about 4–5 °C and transported to the laboratory for the analysis of selected physicochemical parameters and heavy metals.

2.5. WATER SAMPLE DIGESTION

The digestion of water samples was performed according to the standard procedure for determination of the concentration of heavy metals in water samples. All samples of water were taken and then shaken thoroughly prior to digestion. Each sample was taken in a clear conical flask and the volume of each sample was measured as 100 mL and 5 mL of concentrated nitric acid (HNO_3) was added to each sample. The mixture was then gently heated on a hot plate and slowly evaporated to about 20 mL, without letting the sample boil.

Another 5 mL of concentrated nitric acid was added, and the flask was again covered with a watch glass and heated until the solution was clear, indicating that there was quite a bit of oxidation of organic matter. 2 mL of concentrated hydrochloric acid (HCl) was then added to further digest any leftover residues followed by a few drops of hydrogen peroxide (H_2O_2) to fully digest the sample. The digested solution was then left to cool, filtered and transferred to a 100 mL volumetric flask. The volume was then made up to the calibration mark with distilled water and the heavy metal analysis was performed [18, 19].

2.6. PROCEDURE FOR METAL ANALYSIS

All the water samples were analysed for the presence of heavy metal content by Atomic Absorption Spectrophotometry (AAS) following a standard analytical procedure. The appropriate hollow cathode lamp for each metal analysed was used, and the operating current was selected as per the manufacturer's instructions. The wavelength suitable for each metal was selected due to the characteristic absorption wavelength of different elements.

The instrument was calibrated with standard metal solutions of known concentration before the analyses were carried out. Optimum sensitivity and stability of the analytical signal were obtained by adjusting the burner height and the conditions of the acetylene-air flame. The water samples were then transferred from the beaker into the flame by aspirating through the capillary tube and the absorbance values were measured. The concen-

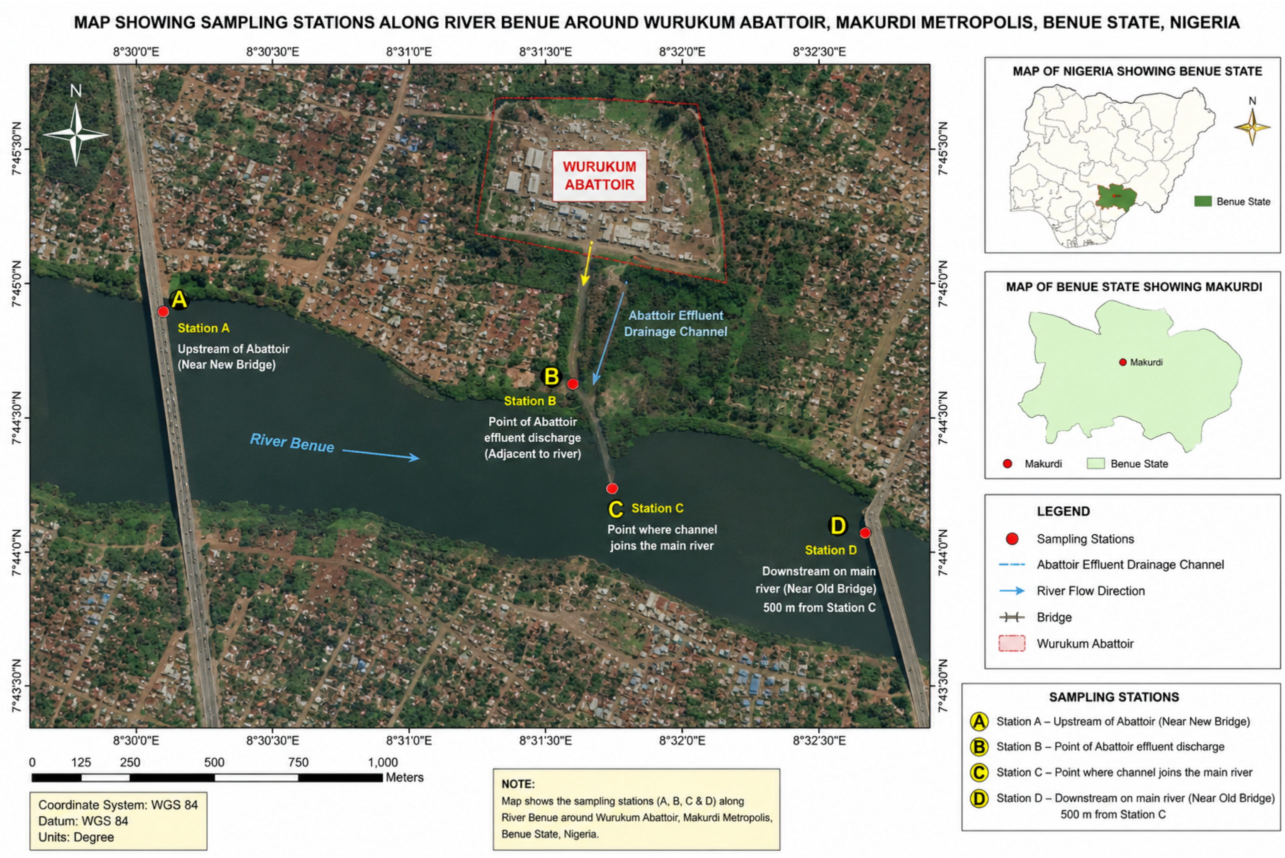


Figure 1. Map of the study area showing the sampling stations along River Benue, Wurukum, Makurdi Metropolis, Benue State, Nigeria. Source: Authors' compilation using ArcGIS 10.8 and field survey data, 2026.

Figure 2. Slaughtering activities and waste-disposal area near the effluent discharge point into River Benue at Wurukum Abattoir, Makurdi. Source: Authors' field survey, 2026.

trations of metals in the samples were then calculated using the comparisons of the absorbance values with the calibration stan-

Figure 3. Section of River Benue and surrounding catchment area used for water sampling at Wurukum, Makurdi Metropolis. Source: Authors' field survey, 2026.

dards [18, 20].

2.7. DETERMINATION OF PHYSICOCHEMICAL PARAMETERS

2.7.1. Determination of temperature

A mercury in glass thermometer marked with degrees was used to take the temperature of the water at each of the sampling points in the field. The thermometer was placed straight into the water samples at a depth of approximately 10–15 cm below the water surface and the temperature readings were taken in the morning peak time of the abattoir, and repeated three times to ensure accuracy.

2.7.2. Determination of pH

The pH of the water samples was measured by a calibrated digital pH meter according to standard method. The pH meter electrode was washed with distilled water before putting it in each sample. pH values were allowed to stabilize prior to readings. Each measurement was repeated three times and the average values were determined.

2.7.3. Determination of electrical conductivity

A digital conductivity meter (HQ14D - HACH, USA) was used to measure electrical conductivity (EC). The conductivity cell was cleaned three times with the sample water before the analysis to reduce the possibility of contamination. The probe was then inserted into the sample and the conductivity reading was taken after the reading had stabilized, in microSiemens per centimeter. It was repeated three times and the temperature was recorded for each time.

2.7.4. Total acidity

The total acidity of the water samples was calculated by titrating 50 mL of the water samples with a standardized sodium hydroxide solution (NaOH) using phenolphthalein as an indicator. A slight, permanent pink coloration was taken as the endpoint. Total acidity was calculated using equation (1) and expressed as mg/L as $CaCO_3$:

$$\text{Total Acidity } (mg/L \ as \ CaCO_3) = \frac{A \times N \times 50,000}{V}, \quad (1)$$

where A is the volume (mL) of standard sodium hydroxide used for titration, N is the normality of the sodium hydroxide solution, and V is the volume (mL) of the water samples analyzed.

2.7.5. Determination of dissolved oxygen (DO)

The dissolved oxygen (DO) was measured by a digital dissolved oxygen meter (YK-22DO, USA). The probe was simply inserted into the sample water, and the reading was taken in mg/L after stabilization.

2.7.6. Determination of biochemical oxygen demand (BOD)

Biochemical Oxygen Demand (BOD) was calculated from the change in dissolved oxygen concentration of freshly collected samples, compared with the dissolved oxygen concentration after incubation in the dark at room temperature for five days. The change in dissolved oxygen levels before and after incubation was the BOD of the sample [18].

2.7.7. Determination of total solids

The total solids content was obtained by evaporating a known volume of the water samples in a pre-weighed evaporating dish, and drying the residue in an oven at 103-105 °C until a constant weight was achieved. Total solids were total dissolved solids (TDS) plus total suspended solids (TSS).

2.7.8. Determination of total hardness

The EDTA titrimetric method was used to determine total hardness. 50 mL of the water samples was placed in a conical flask, followed by the addition of ammonium chloride buffer solution and Eriochrome Black T indicator. The sample was then titrated with 0.01 M EDTA solution till the colour of the sample changed from wine-red to blue colour which indicated the endpoint. The total hardness was calculated using equation (2) and expressed as mg/L as $CaCO_3$:

$$\text{Total Hardness } (mg/L \ as \ CaCO_3) = \frac{A \times N \times 50,000}{V}, \quad (2)$$

where A is the volume (mL) of EDTA used in the titration, N is the normality of the EDTA solution, and V is the volume (mL) of the water sample analyzed.

3. RESULTS AND DISCUSSION

This study assessed the selected physicochemical parameters and heavy metals levels in water samples of River Benue near Wurukum Abattoir, Makurdi, Benue State, Nigeria. The results were then compared to the acceptable levels by the World Health Organization and other regulatory water quality standards. The outcome showed that there were differences in contamination levels associated with activities at the slaughter houses and anthropogenic contribution to the river system.

3.1. PHYSICOCHEMICAL CHARACTERISTICS OF WATER SAMPLES

3.1.1. Temperature

The temperature values recorded across the sampling stations ranged from 28.97 to 29.30°C, with a mean value of 29.09°C (Table 1). There were only small differences in temperature between the sampling stations, indicating little thermal disturbance in the study area. Recorded temperatures are within the range of temperatures that have been reported for tropical freshwater systems and have little likelihood of negatively impacting river ecology. Temperature is a critical factor that affects the physicochemical and biological processes of an aquatic environment, such as microbial activity and the availability of dissolved oxygen. The high-water temperature promotes metabolic processes of the microorganisms, lowers the dissolved oxygen content, and can accelerate chemical reactions in the water bodies [21].

The plots of the results in Tables 1 and 2 are shown in Figures 4-13.

3.1.2. Hydrogen ion concentration (pH)

The pH values of the water samples ranged from 6.3 to 6.8, with a mean value of 6.60. These values fall within the recommended WHO guideline range of 6.5–8.5 for drinking water, except for Station C, which showed a slightly acidic condition. The slightly acidic nature of the water may be associated with the decomposition of organic wastes such as blood, animal tissues, and intestinal contents discharged from the abattoir into the river.

Table 1. Comparative analysis of physicochemical properties of water samples and WHO permissible limits.

Parameter	WA	WB	WC	WD	Range	WHO
Temperature (°C)	29.10 ± 0.32	29.30 ± 0.10	28.97 ± 0.20	28.97 ± 0.20	28.97–29.30	–
pH	6.6 ± 0.20	6.67 ± 0.15	6.3 ± 0.15	6.8 ± 0.10	6.3–6.8	6.5–8.5
Electrical conductivity (μS/cm)	60.33 ± 0.58	90 ± 0.71	30 ± 1.00	49.66 ± 0.58	30–90	250
Total solids (mg/L)	40.36 ± 1.79	60 ± 2.00	49.65 ± 1.00	19.67 ± 1.53	19.67–60	500
Total dissolved solids (mg/L)	0.21 ± 0.03	0.02 ± 0.00	0.01 ± 0.00	0.03 ± 0.00	0.01–0.21	500
Total suspended solids (mg/L)	40.15 ± 1.76	59.98 ± 2.00	49.64 ± 1.00	19.64 ± 1.53	19.64–59.98	500
Total hardness (mg/L)	180 ± 2.00	167 ± 0.00	158 ± 2.00	170 ± 2.00	158–180	–
Dissolved oxygen (mg/L)	2.16 ± 0.21	0.94 ± 0.67	0.98 ± 0.23	1.05 ± 0.13	0.94–2.16	≥5
Biochemical oxygen demand (mg/L)	2.2 ± 0.00	79 ± 1.00	4.3 ± 0.58	4.2 ± 0.10	2.2–79	<5.0
Total acidity (mg/L)	9.2 ± 0.26	8.5 ± 0.40	8.17 ± 0.25	9.6 ± 0.15	8.17–9.6	–

WA = Station A water sample; WB = Station B water sample; WC = Station C water sample; WD = Station D water sample; WHO = World Health Organization guidelines for drinking-water quality.

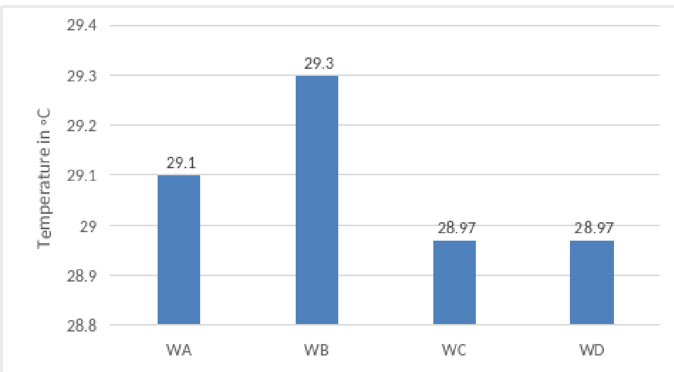


Figure 4. Comparison of temperature levels with WHO standards.

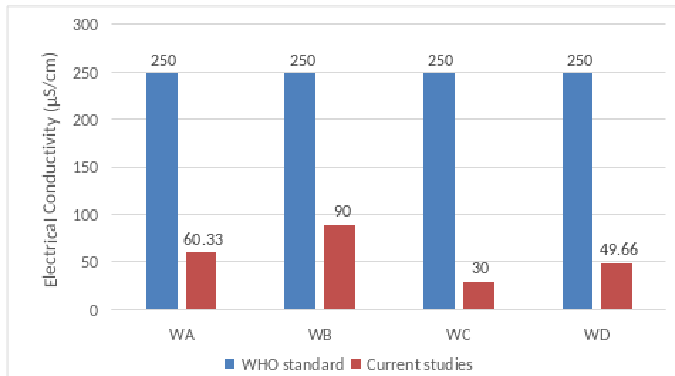


Figure 6. Comparison of electrical conductivity level with WHO standards.

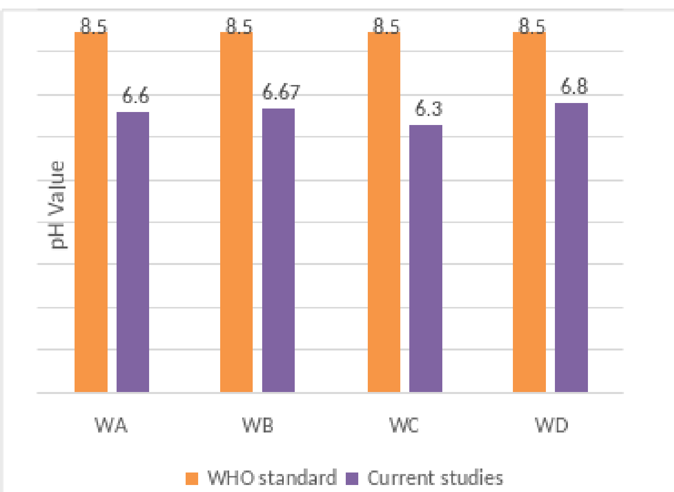


Figure 5. Comparison of pH level with WHO standards.

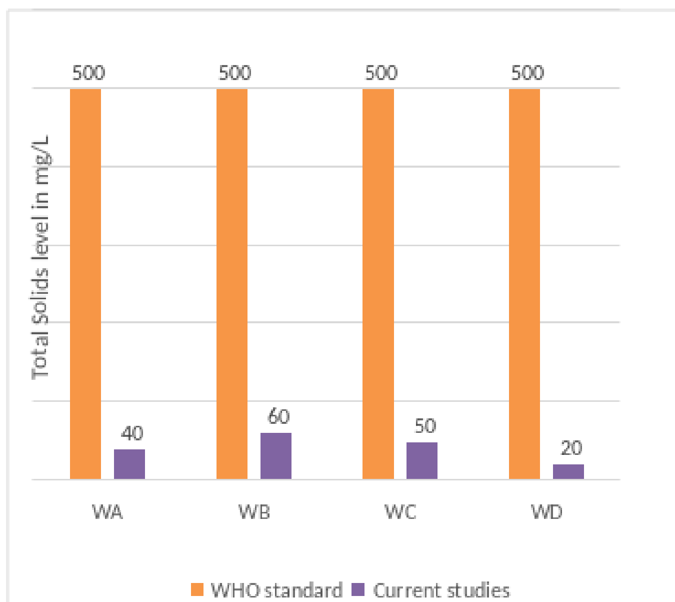


Figure 7. Comparison of total solid level with WHO standards.

The observed pH values place the river water in a moderate category for potable purposes, but further organic pollution could lower the pH and increase the corrosiveness of the water. Similar slightly acidic conditions have been reported for rivers contaminated by abattoirs by Fatunsin *et al.* [11], and they cited microbial degradation of organic material and microbial production of acidic metabolites in receiving waterbodies as the cause of this acidity.

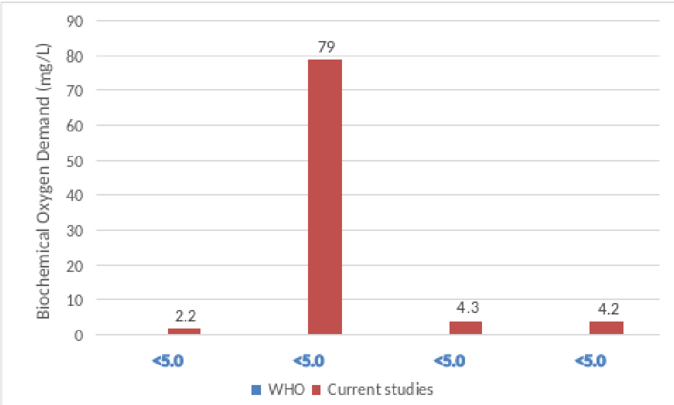


Figure 8. Comparison of biochemical oxygen demand with WHO standards.

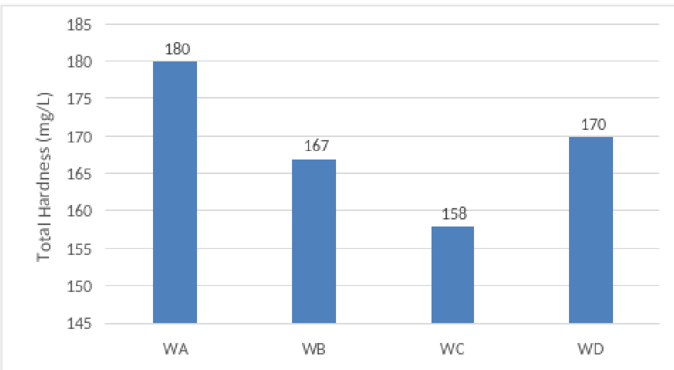


Figure 9. Comparison of total hardness with WHO standards.

Figure 10. Comparison of chromium concentration level with WHO standards.

3.1.3. Electrical conductivity

The electrical conductivity recorded the value which are below the WHO permissible limit of 250 μS/cm. Ranged from 30 to 90 μS/cm, with a mean value of 57.50 μS/cm. The electrical conductivity is the reflection of the concentration of dissolved ionic substances in water, and it is an indication of salinity and mineralization.

The low conductivity values measured were perhaps due to low ionic pollution within the study area despite the impact of abattoir

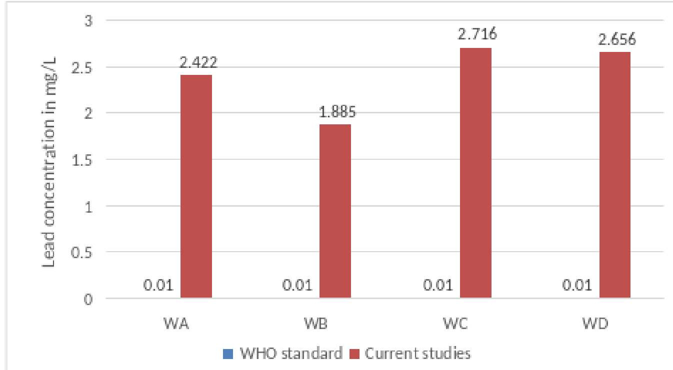


Figure 11. Comparison of lead concentration level with WHO standards.

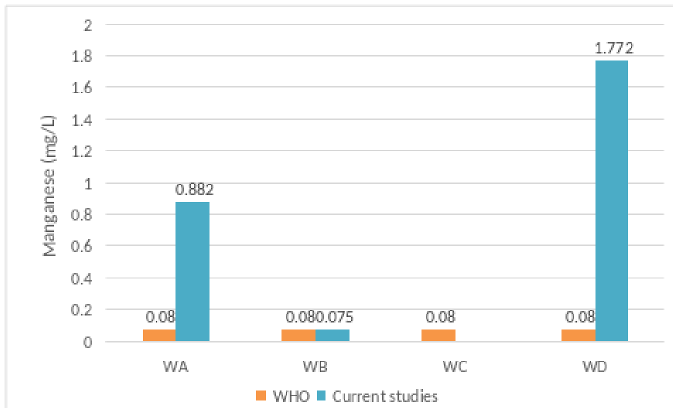


Figure 12. Comparison of manganese concentration level with WHO standards.

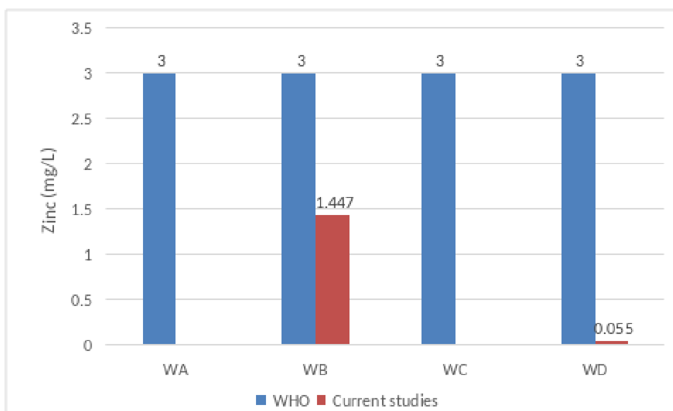


Figure 13. Comparison of zinc concentration level with WHO standards.

waste discharge. However, the comparatively higher conductivity observed at Station B may be linked to direct discharge of organic and inorganic wastes from slaughtering activities. The same was reported by Abasi *et al.* [10], where elevated conductivity values were found around the discharge points of the abattoir, indicating high dissolved salts and decomposing organic matter.

3.1.4. Total suspended solids (TSS) and total solids (TS)

The concentration of total suspended solids (TSS) ranged from 19.64 to 59.98 mg/L, with the highest TSS concentration obtained at Station B, where the abattoir effluent was directly discharged into the water, and the lowest at Station D, which is located downstream of Station B. Likewise, total solids (TS) varied from 19.67 to 60.00 mg/L and had a similar spatial distribution. Similar findings were reported by Omoni *et al.* [14], who observed increased suspended and dissolved solids in the River Benue downstream of abattoir discharge locations. The high TS and TSS levels found at Stations B and C may be attributed to the presence of suspended organic and inorganic material related to abattoir activities and associated runoff. The decrease in the concentrations at Station D can be explained by the natural self-purification, sedimentation, and dilution processes along the river course. Although all TS, TDS, and TSS values were below the World Health Organization (WHO) permissible limit of 500 mg/L for drinking water, the spatial variation among the stations indicates localized impacts of effluent discharge on the river's physical water quality.

3.1.5. Dissolved oxygen (DO) and biochemical oxygen demand (BOD)

The concentration of dissolved oxygen (DO) varied from 0.94 to 2.16 mg/L, with the highest concentration at Station A and the lowest concentration at Station B. The generally low DO levels observed across the sampling stations indicate considerable oxygen consumption associated with the decomposition of organic matter in the river. The minimum level of dissolved oxygen was recorded at station B at direct discharge from the abattoir (0.94 mg/L), indicating high microbial activity due to the high inflow of biodegradable waste.

The biochemical oxygen demand (BOD) obtained varied between 2.2 and 79.0 mg/L. The highest BOD value was recorded at Station B, while the lowest value occurred at Station A. The high BOD at Station B is due to the significant organic contamination provided by abattoir effluents such as blood, animal tissues, fats, and other biodegradable materials. The same findings were observed by Nandomah and Tetteh [9], who found that there was a general occurrence of oxygen depletion and eutrophication in aquatic ecosystems due to abattoir wastewater. The higher a BOD is, the more the microbes are decomposing, which is evident by the lowered dissolved oxygen concentration. Results show that the untreated effluents from abattoirs have a pronounced effect on the oxygen budget of the receiving water body and can pose a threat to aquatic organisms and the health of the water body.

3.1.6. Total hardness

The total hardness values are in the range of 158–180 mg/L, with an average value of 168.75 mg/L. Based on conventional water hardness classifications, water containing 150–300 mg/L as $CaCO_3$ is categorized as hard water. The hardness levels recorded could be due to the presence of naturally occurring and anthropogenic calcium and magnesium salts in the river catchment. Although hardness is not generally considered a direct health concern, elevated hardness may affect the aesthetic quality of water and contribute to scaling in water distribution systems.

Similar hardness values were reported in studies conducted on the River Benue and other abattoir-impacted water bodies in Nigeria.

3.2. *HEAVY METAL CONCENTRATIONS IN WATER SAMPLES*

3.2.1. Chromium (Cr)

The chromium concentrations in the water samples ranged from 0.327 to 0.532 mg/L, with a mean value of 0.428 mg/L (Table 2). The concentration of chromium recorded in all the samples was above the permissible limit set by the World Health Organization (WHO) for drinking water of 0.05 mg/L, showing that there is a high level of contamination of chromium in the study area. The highest chromium concentration (0.532 mg/L) was observed at Station A, the upstream control station, while the lowest concentration (0.327 mg/L) was recorded at Station C.

The presence of a high concentration of chromium in the control station indicates that the contamination of the River Benue with this element is not only due to abattoir activities but might also be from other sources. Rather, the contamination may be derived from a variety of human activities such as urban runoff, agricultural practices, waste disposal in municipal landfills, vehicle exhaust, and other human-related activities upstream in the river catchment. However, with the distribution pattern of chromium, it is possible to conclude that another polluter is contributing to water quality in the study area, as the pollution load from the abattoir has a minor effect compared to other sources of pollution.

Chromium is a potentially toxic heavy metal, and high levels of exposure for long periods can cause adverse health effects, such as kidney damage, liver dysfunction, dermatitis, and carcinogenic risks. High concentrations of chromium have been reported in polluted aquatic ecosystems impacted by industrial, municipal, and abattoir effluents [10]. The results, therefore, highlight the importance of holistic monitoring and management of both point and non-point pollution sources to the River Benue.

3.2.2. Lead (Pb)

The concentration of lead in the water samples ranged from 1.885 to 2.716 mg/L with an average of 2.419 mg/L (Table 2). The results of the measured concentrations have been above the permissible limit set by the World Health Organization (WHO) for the drinking water of 0.01 mg/L, meaning that there is high contamination of lead in the study area. The highest lead concentration (2.716 mg/L) was recorded at Station C, followed by Station D (2.656 mg/L), while Station B recorded the lowest concentration (1.885 mg/L). Interestingly, the upstream control station (WA) also showed a high concentration of lead (2.422 mg/L), indicating that lead contamination had already occurred in the river upstream of the abattoir discharge point.

Lead is a highly toxic metal that can be stored in the biological tissues and cause severe health risks at low levels. Chronic exposure has been linked to neurological diseases, kidney dysfunction, anemia, developmental impairment in children, and damage to the central nervous system. The observed high levels of lead in this study are thus a major environmental and public health problem for the communities relying on the River Benue for domestic, agricultural, and other socioeconomic purposes. Other incidents of high lead levels have been reported in the River Benue and other polluted aquatic environments in Nigeria [14, 22].

3.2.3. Manganese (Mn)

The concentration of manganese in the water samples ranged from not detected (ND) to 1.772 mg/L, with a mean of 0.681

Table 2. Comparative analysis of heavy metal levels in water samples and WHO permissible limits.

Heavy metal	WA	WB	WC	WD	WHO
Cadmium (mg/L)	N/D	N/D	N/D	N/D	0.003
Chromium (mg/L)	0.532 ± 0.001	0.524 ± 0.002	0.327 ± 0.0015	0.328 ± 0.0015	0.05
Zinc (mg/L)	N/D	1.447 ± 0.002	N/D	0.055 ± 0.001	3.00
Lead (mg/L)	2.422 ± 0.001	1.885 ± 0.002	2.716 ± 0.002	2.656 ± 0.002	0.01
Manganese (mg/L)	0.882 ± 0.003	0.075 ± 0.002	N/D	1.772 ± 0.002	0.08

WA = Station A water sample; WB = Station B water sample; WC = Station C water sample; WD = Station D water sample;

WHO = World Health Organization guidelines for drinking-water quality; N/D = not detected.

mg/L (Table 2). The mean concentration exceeded the permissible limits recommended by the World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) for drinking water. Manganese concentration was highest at Station D (1.772 mg/L), followed by Station A (0.882 mg/L), while it was not detected at Station C.

The spatial distribution of manganese suggests that its occurrence in the study area is influenced by both natural and anthropogenic factors. Elevated manganese concentrations may result from the weathering of manganese-bearing minerals, sediment resuspension, urban runoff, agricultural activities, municipal waste inputs, and other human activities within the river catchment. While the abattoir effluent might contribute to the overall pollution load in the river, the pattern of distribution observed suggests that the concentration of manganese in the river cannot be interpreted as being solely the result of abattoir discharge.

Higher levels of manganese in water have been linked to environmental and public health hazards. Long-term exposure to elevated manganese concentrations can have significant adverse effects on water quality, cognitive development, and neurological function. The manganese levels observed in this study are therefore of concern when considering the appropriateness of the water for drinking and the health of aquatic systems. Similar findings have been reported in rivers impacted by agricultural, urban, and slaughterhouse-related activities in developing countries [11].

3.2.4. Zinc (Zn) and Cadmium (Cd)

Zinc was found in some of the sampling stations with concentrations lower than the permissible limit set by WHO (3 mg/L). Zinc is a trace element that is essential for biological processes, but it can cause detrimental effects to aquatic organisms and cause water quality changes at elevated concentrations. No cadmium was found in any of the sampling stations. The absence of cadmium suggests limited contamination from cadmium-containing wastes within the study area. However, persistent environmental monitoring continues to be required because of the toxicity and bioaccumulation of Cd.

4. CONCLUSION

This study evaluated the physicochemical parameters and heavy metal concentrations in the River Benue around the Wurukum Abattoir, Makurdi. The results showed that some of the physicochemical parameters were within limits recommended by WHO, while high concentrations of biochemical oxygen demand, low dissolved oxygen, and high concentrations of lead, chromium, and manganese showed the pollution from the discharge of abattoir effluent.

Based on these findings, the study recommends that long-term unmanaged effluents from abattoirs are detrimental to the health of the river and its inhabitants. Effective wastewater treatment, regular environmental monitoring, and strict enforcement of environmental regulations are recommended to reduce pollution and protect the quality of the River Benue.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The study was self-funded by the authors.

References

[1] T. Bakare-Abidola, J. Olaoye & O. S. Yekinni, "Environmental assessment of heavy metal contamination and physicochemical properties in abattoir wastewater", GSC Advanced Research and Reviews **22** (2025) 92. https://doi.org/10.30574/gscarr.2025.22.3.0067.

[2] I. A. Ololade, A. O. Apata, N. A. Oladoja, O. J. Oloyede, O. O. Ololade, O. P. Asanga & F. F. Oloye, "Occurrence, seasonal distribution and probabilistic source-specific health risk assessment of dissolved trace metals in southwestern rivers, Nigeria", Science of the Total Environment **963** (2025) 178342. https://doi.org/10.1016/j.scitotenv.2024.178342.

[3] World Health Organization, "Drinking-water", 2023. Available online: https://www.who.int/en/news-room/fact-sheets/detail/drinking-water.

[4] C. N. Amaechi-Onyerimma, O. A. F. Wokoma & A. C. Onugha, "Assessment of heavy metal composition of abattoir effluents on the quality of groundwater in Port Harcourt Metropolis, Rivers State", IAU-Journal of Applied and Environmental Biology **1** (2023) 88. https://www.researchgate.net/publication/371671413_ASSESSMENT_OF_HEAVY_METAL_COMPOSITION_OF_ABATTOIR_EFFLUENTS_ON_THE_QUALITY_OF_GROUNDWATER_IN_PORT_HARCOURT_METROPOLIS_RIVERS_STATE.

[5] T. O. Yahaya, E. O. Oladele, I. A. Fatodu, A. Abdulazeez & Y. I. Yeldu, "The concentration and health risk assessment of heavy metals and microorganisms in the groundwater of Lagos, Southwest Nigeria", Journal of Advances in Environmental Health Research **8** (2020) 225. https://doi.org/10.22102/jaehr.2020.245629.1183.

[6] United States Environmental Protection Agency, "Types of nonpoint source pollution", 2026. Available online: https://www.epa.gov/nps/types-nonpoint-source-pollution.

[7] S. Sati, P. K. Sharma, P. Naithani, P. K. Jha, V. Panwar, N. R. Behera, R. Karmakar, Prashant & A. Mittal, "Bioremediation of heavy metals in con-

taminated water: conventional vs. advanced methods'', Frontiers in Water **8** (2026) 1749800. https://doi.org/10.3389/frwa.2026.1749800.

[8] P. Zhang, M. Yang, J. Lan, Y. Huang, J. Zhang, S. Huang, Y. Yang & J. Ru, ''Water quality degradation due to heavy metal contamination: health impacts and eco-friendly approaches for heavy metal remediation'', Toxics **11** (2023) 828. https://doi.org/10.3390/toxics11100828.

[9] S. Nandomah & I. K. Tetteh, ''Potential ecological risk assessment of heavy metals associated with abattoir liquid waste: a narrative and systematic review'', Heliyon **9** (2023) e17359. https://doi.org/10.1016/j.heliyon.2023.e17359.

[10] C. Y. Abasi, O. G. Aliene, E. P. Salvation & O. Nimighaye, ''The impacts of abattoir waste on soil and water quality: a review'', International Journal of Research and Innovation in Applied Science **9** (2024) 72. https://doi.org/10.51584/IJRIAS.2024.911007.

[11] O. T. Fatunsin, I. G. Enenya & P. Ebomese, ''Effect of abattoir activities on the quality of water and surrounding soil of the Anwai River in Asaba, Nigeria'', African Journal of Aquatic Science **48** (2023) 404. https://doi.org/10.2989/16085914.2023.2288346.

[12] O. O. Elemile, D. O. Raphael, D. O. Omole, E. O. Oloruntoba, E. O. Ajayi & N. A. Ohwavborua, ''Assessment of the impact of abattoir effluent on the quality of groundwater in a residential area of Omu-Aran, Nigeria'', Environmental Sciences Europe **31** (2019) 16. https://doi.org/10.1186/s12302-019-0201-5.

[13] P. A. N. Oghonim, S. C. Onuorah, C. S. Onyima, P. N. Idu, B. O. Uba, C. E. Onyekpeze, A. Eseoghene, E. J. Alari, G. Osunde & F. Ottah, ''Public health risk assessment of heavy metal contamination in abattoir wastewater-irrigated soil and edible crops in Agbor, Delta State, Nigeria'', INOSR Applied Sciences **14** (2026) 9. https://doi.org/10.59298/INOSRAS/2026/14.1.917000.

[14] V. T. Omoni, P. O. Bankole, O. Omoche, C. Obida, C. Igben, O. E. Stephen, E. I. Ogwo & D. N. Torjir, ''Evaluation of the effects of abattoir effluent on the physicochemical and bacteriological quality of River Benue, Nigeria'', Environmental Monitoring and Assessment **195** (2023) 146. https://doi.org/10.1007/s10661-022-10768-4.

[15] C. P. Aleru, V. N. Agi, J. Lawson-Ndu & Q. N. Eme, ''Determination of bacterial quality of water in randomly selected swimming pools in Port Harcourt and Obio-Akpo Local Government Areas, Rivers State, Nigeria'', Journal of Medical Science and Clinical Research **9** (2021) 134. https://www.researchgate.net/publication/349104923_Determination_of_Bacterial_Quality_of_Water_in_Randomly_Selected_Swimming_Pools_in_Port_Harcourt_and_Obio-Akpo_Local_Government_Areas_Rivers_State_Nigeria.

[16] World Geodetic Coordinate Database, ''Latitude and longitude of Makurdi, Nigeria'', 2026. Available online: https://latlong.info/nigeria/benue/makurdi?utm_source=chatgpt.com.

[17] Association of Official Analytical Chemists, Official Methods of Analysis of AOAC International, 22nd ed., AOAC International, Rockville, MD, USA, 2023. https://doi.org/10.1093/9780197610145.002.001.

[18] American Public Health Association, American Water Works Association & Water Environment Federation, Standard Methods for the Examination of Water and Wastewater, 24th ed., APHA Press, Washington, DC, USA, 2023. https://www.standardmethods.org/buy/.

[19] United States Environmental Protection Agency, ''Guidelines establishing test procedures for the analysis of pollutants'', 2022. Available online: https://www.epa.gov/cwa-methods?utm_source=chatgpt.com.

[20] Shimadzu Corporation, Atomic absorption spectrophotometry analytical guidebook, Shimadzu Scientific Instruments, Kyoto, Japan, 2021. https://www.shimadzu.com.au/products/elemental-analysis/atomic-absorption-spectroscopy/aa-7000/index.html.

[21] World Health Organization, *Guidelines for Drinking-water Quality*, 4th ed., incorporating the first and second addenda, World Health Organization, Geneva, Switzerland, 2022. Available online: https://www.who.int/publications/i/item/9789240045064.

[22] R. T. Iwar, J. T. Utsev & M. Hassan, ''Assessment of heavy metal and physicochemical pollution loadings of River Benue water at Makurdi using water quality index (WQI) and multivariate statistics'', Applied Water Science **11** (2021) 124. https://doi.org/10.1007/s13201-021-01456-8.