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Impact of abattoirs and local textile (Adire and Kampala) effluents on Yemoja River in Abeokuta, Nigeria

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ABSTRACT

Discharge of untreated wastewater into water bodies pollutes the receiving waters. This study assessed the impact of abattoir and Kampala designers' effluent discharge on the water quality of the Yemoja River in Abeokuta, Nigeria. Twenty-seven water samples collected at three points, covering 180 m length, for 6 months were assessed for physicochemical parameters and metals and compared with the World Health Organization (WHO) and Standard Organization of Nigeria (SON) permissible standards. Most discharge point levels were found to be higher than their corresponding upstream and downstream values. Temperature, turbidity, magnesium, alkalinity, DO, TSS, phosphate, lead, BOD and potassium were found to be higher than normal levels for river water as prescribed by the WHO and SON while parameters like TDS, TS, calcium, chloride, nitrate, sulphate, iron and COD were lower than the standards. The total coliform values were higher than both national and international permissible limits, indicating contamination by human sewage or animal droppings. The water quality index indicated polluted water that is unfit for consumption. Findings from this research indicate that butchering and tie-and-dye activities have impacted river Yemoja water quality. Therefore, wastewater from the abattoir and textile industries be treated before discharge into water bodies.

Key words: discharge, pollutants, runoff, toxic, wastewater, water quality

HIGHLIGHTS

- Temperature, turbidity, Mg, alkalinity, DO, TSS, phosphate, Pb, BOD and K were higher than prescribed normal levels for river water.
- TDS, TS, Ca, Cl, nitrate, sulphate, iron and COD were lower than permissible standards.
- The water quality index indicated polluted water that is unfit for consumption.
- The Yemoja River had been impacted by discharge of abattoir and textile industry effluents.

INTRODUCTION

Previously, the major source of water for the people residing in Abeokuta was the public water supply through Ogun State Water Corporation. However, the water supply scheme has become inadequate due to the constant increase in the population as well as industrial growth in the city. The insufficient network has led to water scarcity in some areas of Abeokuta, which has made it essential for people in the city to look for other means of accessing water to meet their domestic needs. The major substitutes for pipe-borne water are stream water (surface water), rainwater, springs, and shallow hand-dug wells in areas of low and average income.

Surface water is the most recognizable source of water and is easier to contaminate than groundwater. Rainwater runoff is one of the major types of water that contaminate surface water. Rainwater runs along the ground and can pick up things like human and animal faeces as well as harmful chemicals and deposit them in rivers, streams and lakes. Any surface water that is to be used for drinking is often unsafe and must be treated before drinking. The water obtained from streams is basically used for washing, bathing and flushing but some of the inhabitants of Abeokuta indiscriminately use the water for rearing animals, cooking and even drinking without any regard for its quality. Surface water stands the chance of being easily polluted either by natural occurrences or anthropogenic activities; municipal, industrial, agricultural and others. Most pollution stems from the disposal of wastes into the surface water (from industries) (Taiwo *et al.* 2010).

Pollution from discharge of untreated wastewater into surface water bodies has been a growing concern (Zhai *et al.* 2014). The elevated levels of nutrients (nitrogen and phosphorus) in surface water due to pollution accelerate the growth of oxygen-depleting microbes, destroy the aquatic ecosystems and result in eutrophication (Zhang *et al.* 2015; Olanrewaju *et al.* 2023). Eutrophication has many adverse effects on the water body, such as increased biomass of phytoplankton and macrophyte vegetation, loss of commercial and sport fisheries, increased blooms of gelatinous zooplankton (marine environment), growth of benthic and epiphytic algae, increased toxins from bloom-forming algal species, reduced carbon available to food webs, reduced species diversity, increased treatment costs prior to human use, increased taste and odour problems, as well as decreased aesthetic value of the water body (Smith & Schindler 2009; Badruzzaman *et al.* 2012).

In Nigeria, many streams and rivers become polluted as a result of the discharge of untreated wastewater and other organic wastes directly into them (Jaji *et al.* 2007; Obire *et al.* 2008; Arimoro 2009; Osibanjo *et al.* 2011; Ndakara & Ohwo 2023; Olanrewaju *et al.* 2023). One of the major sources of river pollution is livestock production activities (Kato *et al.* 2009), especially in terms of nutrient pollution. Animal faeces and urine can be a source of pollution if not properly managed. If the animals are not housed, there may also be issues of erosion and sediment transport into surface waters due to their grazing activities. The runoff of animal wastes into surface water poses a great risk of pollution (Khaleel *et al.* 1980). The waste from abattoirs, where the animals are slaughtered, poses another risk due to its high biochemical oxygen demand (BOD), nutrients and pathogens content (Matsumura & Mierzwa 2008; Keskes *et al.* 2012; Nandomah & Tetteh 2023).

Abattoirs in Nigeria are usually located near water bodies for easy access to guaranteed water for processing activities (Akan *et al.* 2010). The wastewater generated from the various abattoir activities – abattoir wastewater – typically comprises water generated from cleaning operations, animal blood, dissolved solids, oil and grease, gut contents and urine (Adeyemo *et al.* 2002; Del Nery *et al.* 2007; Nandomah & Tetteh 2023; Olanrewaju *et al.* 2023). The contamination of surface water from abattoir wastewater constitutes significant environmental and health hazards (Omole & Longe 2008; Nandomah & Tetteh 2023).

Abeokuta is noted for the production of local textiles which are popularly known as Adire and Kampala, which have been regarded as the best-known pattern dyed cloths in Nigeria for over a century. The local textiles are made in the form of tye-and-dye. The major production site of this local textile is Itoku (Salami 2001), and Asero (the study area) situated in Abeokuta South Local Government Area of Ogun State; though they are also found in many other areas of Abeokuta. The 'Adire and Kampala' (tie-and-dye) business in Abeokuta provides a substantial contribution to the economy in the form of income, employment and foreign exchange generation.

The major constituents (chemical pollutants) of textile effluents are dyes containing pentachlorophenol, chlorine bleaching, halogen carriers, carcinogenic amines, toxic heavy metals, free formaldehyde, biocides, fire retardants and softeners. Dyes in wastewater have complex and stable structures which make them not easily degradable (Wang *et al.* 2022). For instance, it is usually very difficult to remove synthetic, recalcitrant dyes, such as indigo blue (IB) and indigo carmine (IC), used in denim, from wastewater (Quintero & Cardona 2010; Castillo-Suárez *et al.* 2023). Because heavy metals are often used as oxidizing agents, metal complex dyes, dye stripping agents, fastness improvers and finishers (water repellents, flame retardants, anti-fungal and odour-preventive agents), they act as sources of contamination throughout the entire textile processing (Zeiner *et al.* 2007; Hossain & Rahman 2022). Heavy metals such as chromium, copper, zinc and manganese are common in textile processes for dye fixing through chemical complexation (Paul 2015; Uddin & Sayem 2020; Castillo-Suárez *et al.* 2023). The various effluents which are discharged from the production of local textiles could have adverse effects on the water in the surroundings, such as rivers and shallow wells; and could damage human health, livestock and other biodiversity (Hossain & Rahman 2022). An example is the presence of acids or bases in a water body, which alters the pH value of the water. With consistent prolonged use of untreated water contaminated via the discharge of textile wastewater, conditions such as skin and eye irritation, corneal and conjunctiva lesions, dermatitis and cancer can occur in humans (Castillo-Suárez *et al.* 2023).

This study assessed the level of toxicity of the activities of abattoir and local textile industry effluents as well as the hazard caused to the Yemoja River, Abeokuta, Ogun State; and potentially to those that use it.

MATERIALS AND METHODS

The study area

The Asero abattoir and textile dyeing house are located at Asero, Abeokuta South Local Government Area of Ogun State, Nigeria. Asero lies between latitude 7°10′ and 7°12′N and longitude 3°22′ and 3°24′ E of the Greenwich Meridian. Figure 1pre-presents the map of the study area showing the sampling points. The slaughter and textile dyeing houses are located on about 2 hectares of land with the effluents being discharged directly into the surrounding soil and river. The slaughterhouse is

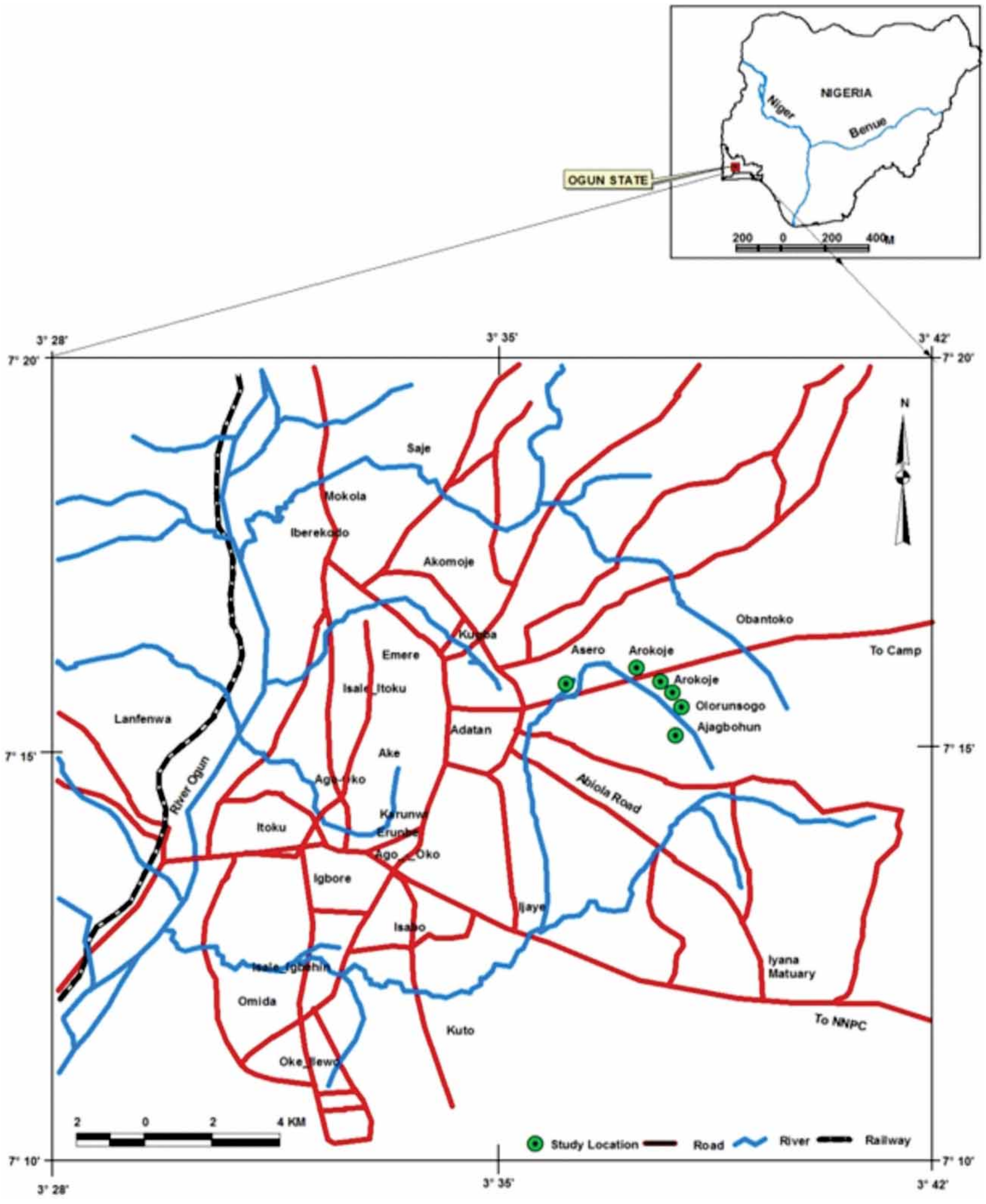

Figure 1 | Map of the study area showing the sampling points.

divided into different sections: the butchering section (where the animals are rendered), the rinsing section (where the parts of the animals are rinsed) and the dung pit (where the intestines are emptied). About 5–10 cows are killed every day. The textile dyeing house is divided into the dyeing and drying sections.

The wastes from the abattoir and textile dyeing house are collectively discharged into the river without treatment. Figures 2 and 3 show discharge of abattoir and textile dyeing wastes into the river Yemoja, respectively.

Sample collection and analyses

Water samples were collected from the Yemoja River where the abattoir and textile industry emptied their effluents directly into the stream, for a period of 6 months. Nine sampling locations were identified from the points before discharge (PBD) (0–60 m) of the abattoir and textile industry wastes, through discharge points (60–120 m), to points after discharge (PAD) (120–180 m). Nine samples were collected through the entire sampling points (about 180 m long) at 20 m intervals for each sampling period; i.e. a total of 81 samples were collected in three different sampling periods (April–May, June–July, August–September, 2016). Samples were collected with white 2-L plastic kegs, which had been thoroughly washed with nitric acid and then rinsed many times with distilled water. Samples for metal analysis were fixed *in situ* with 2 mL concentrated hydrochloric acid while the samples for microbial analysis were collected with sterilized McCartney bottles. All the samples were preserved inside a refrigerator except those for microbial analysis, which were analysed within 24 h.

The laboratory analyses for physical and chemical parameters as well as microbiological analysis were carried out at the Ogun State Water Corporation, Arakanga, Abeokuta, Nigeria. The heavy metals were analysed at the FUNAAB Central Laboratory, Alabata, Abeokuta, Ogun state, Nigeria. The stream pH was determined by using a pH meter (COMBO HI 98130, HANNA, USA), which was standardized with standard buffer 4 and 7 solutions (to near the pH of the water to be tested). The electrode was thoroughly washed with distilled water before measuring the pH of the samples. Water temperature was determined *in situ* using mercury in a glass thermometer and readings were taken at steady temperatures. Turbidity was determined by using a Ultraviolet (UV)-visible spectrophotometer (HACH DR/4000, UK), which was calibrated using

Figure 2 | Discharge of abattoir wastes into the river Yemoja.

Figure 3 | Discharge of textile dyeing wastes into the river Yemoja.

distilled water. A water sample (25 mL) was poured into the cell and turbidity at 860 nm was noted. The result was expressed as a nephelometric turbidity unit (NTU). Electrical conductivity (EC) and total dissolved solids (TDS) were measured *in situ* with a Combo meter (COMBO HI 98130, HANNA, USA), which was inserted into the water samples and the readings were taken after steady points. Total suspended solids (TSS) were determined gravimetrically by measuring 100 mL water sample into a 250 mL Pyrex beaker and filtered through an 11 mm Whatman filter paper of No. 42 equivalent. The filter paper was dried in an oven (UNISCOPE SM 9023, SURGIFRIEND MEDIGALS, UK) set temperature of 105 °C for 30 min. The filter paper was removed and allowed to cool in a desiccator for 15 min. The filter paper was further heated to constant weight within 15 min. TSS was calculated by finding the difference in the initial weight of the filter paper and final weight of the filter paper. The result was expressed as mg TSS per litre of sample. Total solids were evaluated by calculation as sum of TDS and TSS. Dissolved oxygen (DO) measurement was by the electrometric method using an oxygen-detecting electrode (MODEL 970, JENWAY, EU).

The major water ions (Cl^-, NO_3^-, NO_2^-, SO_4^{2-}, PO_4^{3-}, F^-) were analysed using standard procedures:

Chloride (Cl^-)

The Mohr's method (using silver nitrate) was employed in chloride determination. Chloride was determined titrimetrically using 0.025 M silver nitrate and potassium chromate served as an indicator (Vogel 1978). The water sample (100 mL) was measured in a conical flask on a white paper surface and potassium chromate solution (1 mL) was added. Titration was carried out against silver nitrate solution with constant stirring until the slightest reddish colouration appeared which persisted with constant shaking. Blank determination was carried out to allow for the presence of chloride in any of the reagents for the solubility of silver chromate and chloride was calculated as:

$$\mathrm{C1}^-(\mathrm{mg\ L}^{-1}) = \frac{(A - B) \times M \times 70,900}{\text{Volume of sample (mL)}}$$

where A is the volume of silver nitrate solution used for titrating sample (mL), B is the volume of silver nitrate solution used for titrating blank (mL) and M is the molarity of silver nitrate solution.

Potassium (K)

Tetraphenylborate method (0.1–7.0 mg/L) was used to analyse the potassium concentration of the water samples. The graduated mixing cylinder was filled with 25 mL of sample. A round sample cell with 10 mL of sample was filled with the content of one NitraVer 5 Nitrate Reagent powder pillow (this is the prepared sample), stopper and inverting were used several times to mix. The content of one Potassium 3 Reagent pillow was added after the solution cleared. The solution was covered and shook for 30 s. A white turbidity was formed, indicating the presence of potassium. The timer icon was pressed followed by ok. A 3-min reaction period was begun. The solution was poured from a cylinder into a 25 mL sample cell (this is the prepared sample). When the timer beeped, the second sample cell was filled with 25 mL of sample (this is the blank) and the blank was wiped and placed in the cell holder. Zero was touched. The display was shown: 0.0 mg/L within 7 min after the timer beeped, the prepared sample was wiped and placed into the cell holder. Read was touched, then the result appeared in mg/L K.

Nitrate (NO_3^--N)

Cadmium reduction method (0.1–10.0 mg/L NO_3-N) was used to analyse nitrate. A round sample cell with 10 mL of sample was filled with the content of one NitraVer 5 Nitrate Reagent powder pillow (this is the prepared sample). It was capped. The timer icon was touched. Ok was also touched. A 1-min reaction period was initiated, and the cell was vigorously shaken until the timer beeped. When the timer beeped, the timer icon and ok were pressed. A 5-min reaction period was begun. An amber colour was developed indicating that nitrate was present. When the timer beeped, a second round sample cell was filled with 10 mL of sample (this is the blank). The blank was placed into the cell holder. Zero was touched. The display was shown 0.0 mg/L NO_3-N. The prepared sample was wiped and placed into the cell holder. Read was touched. The result appeared in mg/L NO_3-N.

Nitrite (NO_2-N)

Diazotization method (0.002–0.300 mg/L) was used to analyse nitrite. A round sample cell with 10 mL of sample was filled with the content of one NitriVer 3 Nitrite Reagent powder pillow (this is the prepared sample). It was capped and shaken to dissolve. A pink colour was developed indicating that nitrate was present. The timer icon and ok were touched. A 20-min reaction period was initiated. When the timer beeped, a second sample cell was filled with a 10 mL sample (this is the blank). The blank was wiped and placed into the cell holder. The zero was touched. The display was shown as 0.000 mg/L NO_2^--N. The prepared sample was wiped and placed into the cell holder. Read was touched and the results appeared in mg/L NO_2-N.

Phosphate (PO_4^{3-})

Reactive (orthophosphate) (0.02–2.5 mg/L) method was used to analyse phosphate. A sample cell with 10 mL of sample was filled and the content of one PhosVer 3 Phosphate powder pillow was added to the cell. It was capped and inverted to mix (this is the prepared sample). The timer icon and ok were touched. A 2-min reaction period was set up. When the sample was digested using the acid per sulphate digestion, a 10-min reaction period was required. Another sample cell was filled with 10 mL of sample (this is the blank.). When the timer beeped, the blank was wiped and placed into the cell holder. The zero was touched. The display was shown: 0.00 mg/L PO_4^{3-} and the prepared sample was wiped and placed into the cell holder. The read icon was pressed. Results appeared in mg/L PO_4^{3-}.

Sulphate (SO_4^{2-})

SulfaVer 4 method was used to analyse sulphate. A clean sample cell (the prepared sample) was filled and swirled to mix. The timer icon and ok were touched. A 5-min reaction period was initiated. The cell during this time was not disturbed. A second sample cell was filled with 10 mL of sample (the blank). When the timer beeped, the blank was placed into the cell holder. Zero was touched. The display was shown as 0 mg/L. Within 5 min after the timer beeped, the prepared sample was placed into the cell holder. Read was touched and the results were appeared in mg/L SO_4^{2-}.

Fluoride (F^-)

SPADNS 2 method was used to analyse fluoride. The soft key under HACH PROGRAM was pressed. The display was shown: HACH PROGRAM: 1900 Fluoride. 10.0 mL of sample was pipetted into a dry sample cell (the prepared sample). 10.0 mL of de-ionized water was also pipetted into a second dry sample cell (the blank). The pipette filler was used to pipette 2.0 mL of

SPADNS 2 reagent into each cell and swirled to mix. The soft key under START TIMER was pressed. When the timer beeped, the blank was placed into the cell holder. The light shield was closed. The soft key under ZERO was pressed. The display showed: 0.00 mg/L F^-, and the prepared sample was placed into the cell holder. The light shield was closed and results in mg/L F^- were displayed.

Metal analysis

The metals, zinc, copper, lead, nickel, cadmium, sodium and iron, were analysed using a Flame Atomic Absorption Spectrophotometer (Thermo S4AAA) after digestion.

High-purity chemicals were used in all the tests with reagents conforming to the specifications of the Committee on Analytical Reagents of the American Chemical Society. The procedure of digestion involved the transfer of a 50 mL aliquot of well-mixed acidified sample to a 50 mL centrifuge tube and placing it into Mod Block. Then the addition of 2 mL of concentrated HNO_3 and 1 mL of concentrated HCl. The sample was covered with a ribbed watch glass (plastic) and heated at 90 °C until the volume was reduced to 30 mL. The Mod Block was turned off and allowed to cool. The tube walls and glass were washed down with reagent water (18 MΩ). The sample was filtered into a 50 mL volumetric flask to remove silicates and other insoluble materials that could clog the nebulizer. Pre-rinsed 0.45 μm filter attached to a disposable 60 mL syringe was used. The syringe and filter were rinsed with reagent water into a flask. The final volume was adjusted to 50 mL with reagent water.

Background information about the Atomic Absorption Spectrophotometry (AAS) instrument and percent recovery; showing the limit of detection (LOD) or limit of quantification (LOQ) values of metal ions, are presented in Table S1 in the supplementary information file. The procedure followed measuring 100 mL water samples into a clean 250 mL Erlenmeyer flask. A 10 mL acid was added. The mixture was heated on a hotplate for 30 min. The digested samples were filtered and read for metals.

Total coliform

Total coliform (TC) was determined by plate count method (Ademoroti 1996). The ethylene myosin blue agar for TC count was prepared by dissolving 30 g in sterilized distilled water. The solution of the agar was sterilized in an autoclave to form a gel, which was poured into the disposable petri dishes. After the agar had solidified inside the petri dish, the water samples were carefully collected with sterilized McCartney bottles. Next, 0.1 mL of each water sample was transferred into the petri dish containing the solidified agar and incubated at 37 °C in Sanyo Gallenkamp incubator (INC 200 230T, ARTISAN SCIENTIFIC, UK) for 24 h for coliform growth. The blue metallic shining colonies produced were counted and calculated as follows:

$$\text{Total coliforms/100mL} = \frac{\text{Coliform count} \times 100}{\text{Vol. (mL) sample introduced to the Petri dish}}$$

Data analysis

Data collected were analysed for descriptive (mean and standard deviation) and inferential (Duncan multiple range test, principal component analysis, regression model) statistics using SPSS for Windows software package (version 23.0).

Determination of water quality index

The water quality index (WQI) method was adopted to assess the suitability of the groundwater for drinking purposes. This method uses parameters such as the water quality rating scale, relative weight and sub-index WQI to calculate the overall WQI (Saana *et al.* 2016). In this present study, the WQI was estimated from 18 groundwater parameters (Table S2 in the supplementary material).

Water quality rating scale, Q_i was estimated as:

$$Q_i = \frac{C_n}{S_n} \times 100 \quad (1)$$

where C_n is the concentration of each (nth) parameter, S_n is the standard value of each (nth) parameter.

Relative weight, W_n was calculated as:

$$W_n = \frac{W_n}{\sum_{n=1}^{y} W_n} \quad (2)$$

where w_n is the weight of each (nth) parameter and y is the number of parameters.

The overall WQI was estimated:

$$\mathrm{SI}_n = W_n \times Q_n \quad (3)$$

where SI_n is the sub-index of nth parameter, Q_n is the water quality rating scale and W_n is the relative weight.

$$\mathrm{WQI} = \sum \mathrm{SI}_n \quad (4)$$

WQI < 50 is the excellent water quality; WQI 50.1–100 is the good water quality; WQI 100.1–200 is the poor water quality; WQI 200.1–300 is the very poor water quality; while WQI > 300 is the water unfit for drinking (Ramakrishnaiah *et al.* 2009).

RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics based on means for the physical and chemical parameters of the water samples from the Yemoja River. Water temperature varied from 30.0 to 30.6 °C among sampling points; PBD, Points of discharge (PD) and PAD before the month of August. Decomposition of organic matter by coliforms could lead to heat generation and this might have contributed to the high water temperature (Taiwo *et al.* 2010). Generally, the water temperature was higher than the Standards Organization of Nigeria (SON 2007) and World Health Organization (WHO 2008) standards of 25 °C in natural water, thereby indicating thermal pollution of the stream (Hossain & Rahman 2022). Meanwhile, temperature values were still within the range for tropical aquatic systems (<40 °C) (Adeogun *et al.* 2011).

There are patterns of pH values variation between the three sample collection points. The highest value was experienced at PAD in June–July and the lowest values were at PBD in August–September. This could be as a result of the increase in algae populations (which made the water greenish in colour) by their photosynthetic activity which could have increased the number of hydroxyl ions (Terrumun & Oliver 2015). The pH of the Yemoja River is slightly alkaline with pH values ranging between 7.25 and 7.48. All the pH values are within the WHO (2008) and SON (2007) recommended range of pH values (6.5–8.5) for surface and drinking water.

The DO is a quantifying of the degree of pollution by organic matter, the demolition of organic substances as well as the self-cleansing ability of the water body. The DO obtained, as shown in Table 1 among PBD, PD and PAD for the months of April and May varied between 4.31 and 7.13 mg/L, for the months of June and July between 5.82 and 6.80 mg/L and for the months of August and September between 4.69 and 5.16 mg/L, respectively. The standard for sustaining aquatic biological life is predetermined to be 5.0 mg/L (SON 2007); a concentration below this adversely affects aquatic biological life, while a concentration below 2.0 mg/L may lead to the death of most aquatic life (Terrumun & Oliver 2015; Hossain & Rahman 2022). The DO levels (4.31 and 4.78 mg/L) at the PD of abattoir and textile effluents for April–May and August–September as well as the DO level (4.69 mg/L) at the PAD in August–September were found to be slightly below the levels required for the sustenance of most aquatic life. The low levels of DO at those specific points of the stream might be related openly to the high value of nutrients observed from the stream with subsequent high coliform populations which might have reduced the DO (Awomeso *et al.* 2010; Hossain & Rahman 2022). Thus, the lower values recorded for DO at the PD in this study could have been a result of the increased amount of organic loads due to the effluents being discharged at those points, placing higher demands on oxygen for chemical oxidation, nutrients decomposition or break down, depleting available oxygen for respiration. Minna and Ogun rivers produced similar results due to the discharge of abattoir effluents (Chukwu *et al.* 2008; Adeogun *et al.* 2011).

EC of the stream (405.33–455.0 μScm^{-1}) at different sampling points was generally lower than the SON standard given as 1,000 μScm^{-1} (SON 2007). This is in conformation with the result of Neboh *et al.* (2013), who recorded a low level of EC at Ijebu-Igbo river (Abattoir effluent). This is unlike most studies recording high EC for rivers taking effluent discharges.

Table 1 | Descriptive statistics based on means for the physical and chemical parameters of the Yemoja River

Parameter	PBD Apr–May	PD Apr–May	PAD Apr–May	PBD Jun–Jul	PD Jun–Jul	PAD Jun–Jul	PBD Aug–Sep	PD Aug–Sep	PAD Aug–Sep
Temperature (°C)	30.2 ± 0.87	30.4 ± 1.64	30.0 ± 0.35	30.0 ± 1.01	30.3 ± 0.90	30.2 ± 0.40	26.5 ± 1.80	26.2 ± 0.88	26.2 ± 0.66
pH	7.33 ± 0.55	7.47 ± 1.63	7.37 ± 0.05	7.40 ± 1.23	7.40 ± 0.69	7.48 ± 0.50	7.25 ± 1.44	7.27 ± 1.47	7.28 ± 0.74
Dissolved oxygen (mg/L)	5.72 ± 0.67	4.31 ± 0.65	7.13 ± 1.13	5.82 ± 0.49	5.86 ± 0.05	6.8 ± 1.02	5.16 ± 0.32	4.78 ± 0.80	4.69 ± 0.59
Electrical conductivity (μS/cm)	452 ± 7.46	455 ± 6.85	443.33 ± 6.03	447.67 ± 6.67	433.67 ± 7.09	422.67 ± 9.54	410 ± 4.60	403.67 ± 6.70	405.33 ± 6.12
Turbidity (NTU)	3.08 ± 1.84	10.03 ± 0.40	5.28 ± 1.28	2.77 ± 0.64	6.0 ± 1.92	11.79 ± 1.17	7.31 ± 1.51	8.97 ± 1.07	7.90 ± 0.27
Total solids (mg/L)	460 ± 7.03	413 ± 9.93	433 ± 8.37	421 ± 5.84	458 ± 8.15	424 ± 6.05	419 ± 7.14	416 ± 7.61	397 ± 4.81
Total dissolved solids (mg/L)	167 ± 5.25	160 ± 4.22	201 ± 4.72	202 ± 4.85	199 ± 4.87	193 ± 4.93	189 ± 5.89	184 ± 5.50	189 ± 5.47
Total suspended solids (mg/L)	293 ± 7.64	253 ± 9.18	232 ± 8.61	218 ± 11.40	260 ± 8.49	230 ± 9.26	226 ± 9.90	228 ± 9.53	209 ± 6.32
Calcium (mg/L)	154 ± 19.05	146 ± 18.76	156 ± 19.45	39 ± 19.59	38.67 ± 19.45	40 ± 21.20	35.67 ± 18.50	38 ± 20.41	34 ± 19.30
Magnesium (mg/L)	45.33 ± 6.26	52 ± 2.82	42.67 ± 4.60	17.33 ± 4.69	17.33 ± 4.15	18.67 ± 5.25	21.33 ± 4.57	21 ± 4.53	19.33 ± 3.82
Alkalinity	15.33 ± 1.00	17.33 ± 2.44	16.67 ± 1.10	25.0 ± 2.28	22.33 ± 0.94	27.33 ± 2.42	20 ± 1.28	21.67 ± 1.27	21.33 ± 3.07
Chloride (mg/L)	37.67 ± 8.78	39 ± 8.32	42.33 ± 8.07	108.67 ± 8.87	98 ± 8.85	99.33 ± 8.58	76.33 ± 9.49	77.67 ± 10.01	73 ± 11.66
Iron (mg/L)	0.038 ± 0.04	0.212 ± 0.29	0.103 ± 0.72	0.05 ± 1.47	0.1 ± 0.79	0.15 ± 0.73	0.107 ± 0.23	0.15 ± 2.07	0.1 ± 0.11
Nitrate (mg/L)	0.64 ± 1.50	2.90 ± 0.33	2.07 ± 2.16	4.13 ± 0.37	4.53 ± 1.71	4.17 ± 0.50	7.0 ± 0.79	7.16 ± 1.45	7.07 ± 1.37
Nitrite (mg/L)	0.08 ± 0.26	0.09 ± 1.54	0.08 ± 0.04	0.09 ± 0.09	0.08 ± 0.33	0.09 ± 0.70	0.09 ± 0.15	0.09 ± 0.56	0.09 ± 1.63
Sulphate (mg/L)	15.54 ± 0.44	33.33 ± 0.88	27.42 ± 2.77	16.67 ± 3.65	30.00 ± 1.85	18.67 ± 2.40	15.00 ± 1.63	16.33 ± 3.73	15.67 ± 2.51
Chromium (mg/L)	0.04 ± 0.03	0.04 ± 0.80	0.02 ± 1.01	0.01 ± 0.78	0.05 ± 0.63	0.02 ± 0.20	0.02 ± 0.74	0.03 ± 2.29	0.02 ± 0.01
Phosphate (mg/L)	0.20 ± 1.53	0.30 ± 1.86	0.20 ± 0.40	1.10 ± 0.46	0.96 ± 0.70	0.63 ± 1.82	0.58 ± 0.17	0.66 ± 0.96	0.87 ± 0.48
Sodium (mg/L)	18.00 ± 0.57	19.33 ± 0.96	20.00 ± 0.19	19.33 ± 2.69	27.67 ± 0.25	23.00 ± 1.51	19.33 ± 2.25	24.67 ± 1.09	18.67 ± 1.57
Potassium (mg/L)	5.00 ± 2.54	5.67 ± 0.42	5.00 ± 0.57	4.33 ± 0.26	8.67 ± 1.77	5.67 ± 0.70	5.33 ± 0.45	9.67 ± 2.20	7.67 ± 0.44
Zinc (mg/L)	0.65 ± 1.54	1.86 ± 0.44	1.05 ± 0.33	0.32 ± 1.94	0.53 ± 0.97	0.35 ± 0.03	0.27 ± 1.49	0.36 ± 0.53	0.30 ± 0.18
Lead (mg/L)	0.001 ± 0.91	0.005 ± 0.47	0.002 ± 0.65	0.01 ± 0.51	0.02 ± 0.28	0.012 ± 0.98	0.01 ± 0.00	0.013 ± 0.33	0.01 ± 1.30
Biological oxygen demand (mg/L)	135.67 ± 11.62	180 ± 11.54	173 ± 11.28	151.33 ± 11.59	155.33 ± 11.42	143.33 ± 11.42	143.33 ± 11.32	158.33 ± 11.43	183 ± 11.51
Chemical oxygen demand (mg/L)	40 ± 1.65	400 ± 1.46	175 ± 1.81	58 ± 1.68	64.33 ± 1.71	53.67 ± 1.70	65.33 ± 1.56	69.33 ± 1.77	77.33 ± 1.73

PBD, point before discharge; PD, point discharge; PAD, point after discharge.

Turbidity value of the stream was found to vary from 2.77 to 11.79 NTU. All the PD values vary from 6.0 to 11.79 NTU and PAD from 5.28 to 7.90 NTU; which were generally higher than the SON and WHO standards given as 5 NTU (SON 2007; WHO 2008). PBD values conformed to the standard, though slightly high in the months of August–September. Awomeso *et al.* (2019), from their study of the Ogun River Basin covering the Ogun, Ofiki, Opeki and Oyan rivers also reported higher mean concentrations of turbidity (49.7 ± 13.0 NTU) and TSS ($1,205.2 \pm 4.7$ mg/L) than the permissible WHO limits of the drinking water. The high level of turbidity in the water samples; which is indicative of the presence of colloidal solids and a large number of micro-organisms, may result in the unpleasant colour of the water and may also be harmful. Turbidity also influences the penetration of light, which in turn affects the photosynthetic activity of plants and the productivity of the river.

The amount of solids in the stream/river was lower throughout the sampling sites than the SON and WHO standards given as 2,000 mg/L (SON 2007; WHO 2008). At the PBD, total solid (TS) was in the range of 419–460 mg/L, TDS: 167–202 mg/L and TSS: 218–293 mg/L. At the PD; TS was in the range of 413–458 mg/L, TDS: 160–199 mg/L and TSS: 228–260 mg/L. At the PAD; TS was in the range of 397–433 mg/L, TDS: 189–201 mg/L and TSS: 209–232 mg/L. WHO (2008) has recommended TSS, TDS and TS values of 20–80, 500 and 2,000, respectively, in drinking water. The levels of TDS and TS in this stream were lower than the WHO value while that of TSS was greater than the WHO value. This is attributable to increased runoff inflow from the catchment area from the months of July–August, and reduced dilution of the river water from October to December when there was no more rainfall (Terrumun & Oliver 2015). TS is not deemed to be associated with health effects, but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants (WHO 2008). Therefore, effluents from textile and abattoir industries are capable of increasing the TSS of water bodies.

Calcium levels of the stream were found to vary from 34.0 to 156.0 mg/L in all sampling points and were found to be generally lower than the SON and WHO standard given as 200 mg/L (SON 2007; WHO 2008).

Magnesium values were observed to range between 17.33 and 52.0 mg/L throughout the sampling stations. Mg values were very much higher than the permissible limits, 0.20 mg/L as prescribed by WHO (2008). Calcium and magnesium (hardness) normally come from weathering of bedrock. It has no health effect except consumer acceptability (SON 2007). This might reach the water body as a result of the effects of textile effluents which might facilitate the weathering of the bedrock.

The stream has alkalinity ranging between 15.33 and 27.33 mg/L throughout the sampling points before and after the discharge points, recording high values, especially towards the dry period. The use of soaps during textile production might have increased the concentration of carbonates and hence the alkalinity of the stream (Awomeso *et al.* 2010).

Chloride was found to range between 37.67 and 108.67 mg/L throughout the sampling sites of the stream. Nigeria's drinking water standards (SON 2007) and WHO (2008) require chloride levels not to exceed 250 mg/L. Thus, the lowest and highest mean values of chloride observed at all the sampling points were lower than the permissible limits prescribed. Nitrate of the stream varied from 0.64 to 7.16 mg/L at all sampling points and was found to be generally lower than SON and WHO standard given as 50 mg/L (SON 2007; WHO 2008). Nitrite of the stream ranged between 0.08 and 0.09 mg/L in all sampling points (with no significant variation through the months) and was found to be generally lower than SON and WHO standard given as 0.2 mg/L (SON 2007; WHO 2008). This is an indication that both abattoir and textile effluents did not alter the concentration of nitrite, which was negligible during the period covered in this study. Clagnan *et al.* (2021) also reported negligible nitrite concentration in inlet textile wastewater during their experimental period. Even lower, negligible concentration (<0.02 mg/L) was reported by Nwankwoala *et al.* (2009) for abattoir effluent unaffected and affected surface water during the wet season in Nigeria. Studies have shown that nitrites can bring about brown blood disease in fish as well as react directly with haemoglobin in the blood of humans and other warm-blooded animals to produce methaemoglobin which destroys the oxygen transportation ability of red blood cells (Nwankwoala *et al.* 2009). In this case, there is no cause for fear since the concentrations were negligible.

Rapid conversion of nitrates to nitrites is expected during wet seasons as a result of low oxygen tension due to saturation with water in the wet season, and hence, greater accumulation of nitrite than nitrate is expected in the wet season. Our result, however, shows otherwise, which could have been because during the wet season, both the soil temperature and oxygen tension are low (higher soil temperatures favour conversion of nitrate to nitrite), bringing about greater accumulation of nitrate as observed (Nwankwoala *et al.* 2009).

Sulphate of the stream varied from 15.00 to 33.33 mg/L in all sampling points and was found to be generally lower than the prescribed standard of 100 mg/L (SON 2007; WHO 2008) by SON and WHO. Phosphate values of the stream varied from 0.20 to 1.10 mg/L throughout the sampling points and were found to be generally higher than the WHO standard given as 0.1 mg/L (WHO 2008). Phosphate has no health effect but it has environmental effects in terms of nutrient enrichment of surface water. The result obtained in this study is far above the standard, indicating that the stream is polluted. The high phosphate value of a stream could also lead to oxygen reduction with subsequent effects on aquatic organisms (Awomeso *et al.* 2010). Terrumun & Oliver (2015) also reported an excess phosphate as an impact of the discharge of abattoir effluents in a water body. Phosphorus is one of the nutrients that cause eutrophication in water bodies which effectively reduces the DO of the water body.

Chromium of the stream ranged between 0.01 and 0.05 mg/L throughout the sampling points and was found to generally conform to the standard prescribed by the SON and WHO given as 0.05 mg/L (SON 2007; WHO 2008). The levels of iron recorded in the stream were in the range between 0.034 and 0.212. Iron levels were found to be lower than the permissible limit (0.3 mg/L) as prescribed by WHO (2008). The sodium of the stream ranged from 18.00 to 27.67 mg/L throughout the sampling points and was found to be generally lower than the standard prescribed (200 mg/L) by the SON and WHO (SON 2007; WHO 2008). The least value of potassium (4.33 mg/L) was observed at PBD in June–July and the highest value (9.67 mg/L) at PD in August–September.

Potassium values were generally high in the studied river especially at the discharge points and the points after the discharge, showing indication of the influence of the wastewater/effluents. Most natural surface waters have been reported to contain less than 5 mg/L (Skowron *et al.* 2018). The potassium may have come from animal wastes since potassium is an essential macro-nutrient for animals. Matheyarasu *et al.* (2016) reported an increase in soil fertility as evident from significantly increased biomass yield and plant height in all the tested plants due to irrigation using nutrient-rich abattoir wastewater. They reported that the soil irrigated with abattoir wastewater had a significant increase in both macronutrients (N, P, K) and micronutrients (Ca, Mg, Zn, Fe, Al, Bo) when compared to the non-irrigated control samples. They concluded that the use of abattoir wastewater increased nutrient availability to the plants. Meanwhile, artificial textile wastewater contains potassium compounds (Yaseen & Scholz 2019).

Zinc of the river had the highest concentration of 1.86 mg/L at PD in April–May and the least concentration of 0.27 mg/L at PBD August–September and was found to be generally lower than the standard prescribed (3 mg/L) by the SON and WHO (SON 2007; WHO 2008). It was observed that the concentration of zinc was relatively high between April and May and low for the remaining months of the wet season. The presence of zinc in surface water in Nigeria has been shown to be seasonal – high in dry seasons and low in wet; attributable to variations in precipitation (Eliku & Leta 2018). Zinc in the Calabar river, Nigeria had been observed by Ewa *et al.* (2013) to be relatively high in the dry season, but low in the wet. Edward & Adamu (2023) also observed a similar trend in Nigeria, recording the highest concentration of Zinc in April, with lower concentrations in the following months of the wet season; the least value in June. This result shows that the river water, as it concerns zinc, is adequate for aquatic life as well as domestic uses (Iwara *et al.* 2012; Ewa *et al.* 2013)

Lead values of the river ranged between 0.001 (at PBD, April–May) and 0.02 mg/L (at PD, June–July) throughout the sampling points. Lead levels at the POD were found to be higher than the standard prescribed (0.01 mg/L) by the SON and WHO (SON 2007; WHO 2008) during the period. High levels of lead in the water samples, which in humans can negatively affect haemoglobin synthesis, cause problems in kidneys, joints, gastrointestinal and reproductive systems, and lead to acute and chronic nervous system impairment, could have been a result of untreated contamination via abattoir and textile industry effluents (Nandomah & Tetteh 2023). Higher concentrations of phosphate (1.14 ± 1.3 mg/L), cadmium (0.02 ± 0.01 mg/L) and lead (0.33 ± 0.05 mg/L) than the permissible WHO limits were also revealed for the Ogun river basin by Awomeso *et al.* (2019) who attributed the pollution via varimax rotated Principal Component Analysis (PCA) to industrial effluents, runoff, fertilizer and dissolved salts. This is in agreement with other studies from which food (locust beans) processing, textile dyeing/making and mining as well as poultry and abattoir wastes had been attributed to be major sources of water pollution in the southwestern part of Nigeria (Taiwo *et al.* 2013; Ayantobo *et al.* 2014; Ojekunle *et al.* 2014; Taiwo & Awomeso 2017).

The value of biological oxygen demand (BOD) of the studied river varied between 135 and 183 mg/L. Samples taken at the discharge point (PD) in the months of April/May and June/July and the samples taken after the discharge point in September/August recorded the highest BOD values. Most of the sites have high values of BOD which extremely exceeded the permissible standard of BOD in drinking water (10 mg/L). High BOD in water indicates the presence of biologically resistant organic substances (Awomeso *et al.* 2010). The prominent values of BOD in this study were in line with the study of Omole & Longe (2008) who found a high value of BOD in river Illo, Ota, Nigeria as an impact of abattoir waste. Therefore, high values of BOD at all sampling points showed high levels of decomposable organic matter (Abdullahi *et al.* 2021; Nandomah & Tetteh 2023), which is an indication that the effluents impacted the river. The higher the BOD value, the more the microbes, the lower the DO value and the lower the water quality (Abdullahi *et al.* 2021). Textile industries wastewater/effluents are highly coloured and saline, containing high amounts of organic and inorganic pollutants, non-biodegradable compounds with high values of biological oxygen demand (BOD) and chemical oxygen demand (COD) (Dey & Islam 2015; Shrivastava & Singh 2021). Fibre residues and suspended solids in textile effluents are also responsible for high BOD values (Dey & Islam 2015).

COD refers to the quantity of oxygen required to break down the chemical pollutants in the river, and hence, the more chemical pollutants, the higher the COD; and the higher the dangers of losing freshwater organisms (Durotoye Taiwo *et al.* 2018). The value of COD of the studied stream varied between 40 and 400 mg/L. Samples taken at the point of discharge in the months of April and May and the samples taken at a PAD in the same months recorded the highest COD values (400 and 175 mg/L, respectively). Abattoir and textile industry effluents contributed to the high COD at those discharge points. According to Kundu *et al.* (2013), blood, which is a major dissolved pollutant in abattoir wastewater, has the highest COD of all abattoir effluents. COD in this study could have also been raised due to formaldehyde-based dyes, softeners and detergents which are present in textile wastewater (Elango & Elango 2017; Durotoye Taiwo *et al.* 2018). All the other sites had low values of COD compared with the permissible standard of COD in drinking water (100 mg/L) as prescribed by WHO (WHO 2008). These low values were probably due to increased precipitation, water and river flow, in those months.

Adeogun *et al.* (2011) from their study on the impact of abattoir and saw-mill effluents on the water quality of Ogun river (Abeokuta) recorded higher values for most of the parameters measured in this study; except for temperature and chloride. From their results, they concluded that unless the pollution trends changed, sustainable fisheries in the Ogun river were highly threatened by the elevated values of the physicochemical parameters.

TC of the stream was too numerous to count for all sampling sites. Generally, the coliform values were higher when compared with both national and international permissible limits. WHO has recommended 0 cfu/mL in drinking water while SON (SON 2007) gave coliform value of 400 MPN/mL in effluents. The presence of TC in water is an indication of contamination by human sewage or animal droppings which could contain disease-causing organisms (Awomeso *et al.* 2010; Ndukwe *et al.* 2023).

Figure 4 presents the WQI of the Yemoja River. The mean WQI values were 439 ± 18, 508 ± 39 and 504 ± 55 at sites PBD, PD and PAD, respectively. Even though these values were generally higher than 300, which indicates unfit for consumption of water (Ramakrishnaiah *et al.* 2009); the discharge point (PD) showed the highest WQI. The high WQI values observed at the upstream (PBD) and downstream (PAD) monitoring sites could be explained by additional human activities. In this study, BOD was the major contributor to the high levels of WQI values in the river. This further establishes the impact of organic wastes, which could be traced to the activities of the abattoirs (Taiwo *et al.* 2013; Matheyarasu *et al.* 2016).

It is essential for relevant agencies to monitor abattoir and textile activities or processes so as to curb environmental and health hazards, also prevent critical outbreaks in the near future (Ndukwe *et al.* 2023). It is important to remove toxicity from wastewater to minimize, or entirely remove the potential adverse health effects when wastewater is discharged into river water or is reused for other industrial or agricultural purposes (Abdel-Karim *et al.* 2021; Wang *et al.* 2022). Non-biological processes as well as biological treatment processes, which are eco-friendly and cost-effective are considered to be the best methods for treating abattoir and textile effluents. However, since the organic matter present in textile wastewater is mostly non-biodegradable and difficult to degrade via biotreatment methods, different combinations of treatment methods, such as combinations of coagulation-flocculation–nanofiltration (CF–NF), advanced oxidation processes (AOPs) and microbial fuel cells (MFC) have been used to treat textile wastewater (Shrivastava & Singh 2021; Wang *et al.* 2022). Combining biological and non-biological approaches in treating the wastewater to remove the contaminants from the water would result in greater efficiency (Moreroa & Basitere 2022). These processes, and others that are recently developed are therefore recommended in order to keep aquatic life safe, and the water adequate for drinking and other purposes.

This study revealed that the Yemoja River had been impacted by the discharge of abattoir wastes and textile effluents. It is recommended that the river water be treated before use for drinking, domestic or any other purpose. The effluents can also be treated before discharge into the river.

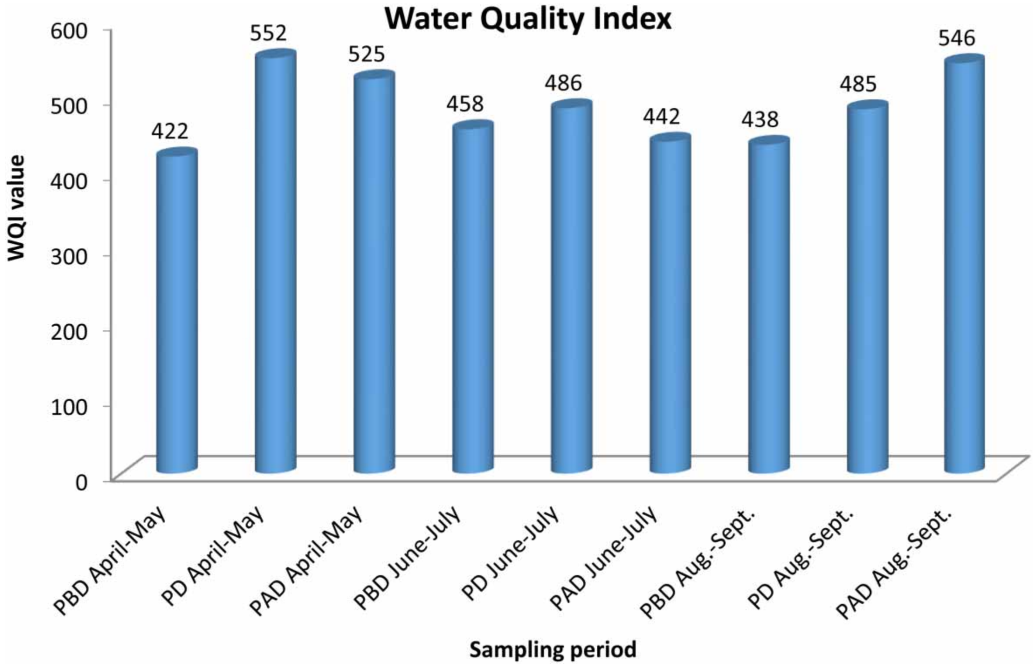

Figure 4 | Water quality index of the Yemoji River; PBD, point before discharge; PD, point discharge; PAD, point after discharge.

CONCLUSION

The effects of abattoir and textile wastewater discharge into the river Yemoja on its water quality were assessed through water quality monitoring. To assess the level of toxic parameters discharged into the river, temperature, TS, TSS, iron, potassium, nitrite, zinc, lead, BOD and COD were used, among others. Temperature, turbidity, Mg, alkalinity, DO, TSS, phosphate, lead, BOD and K were in excess of normal levels for river water as prescribed by the WHO and Standard Organization of Nigeria while parameters like TDS, TS, Ca, Cl, nitrate, SO_4^{2-}, iron and COD were confirmed to be lower than the permissible standards. Findings from this research indicate that butchering activities and tie-and-dye activities in the textile industries have impacted river Yemoja water quality. The dilution of the high-strength rainfall and surface runoff in the river water was not enough to reduce the parameters to acceptable levels. The WQI indicated polluted water that is unfit for consumption. Although there is a potential that an improvement of the water quality may be observed further downstream due to self-purification and further dilution effects, the high levels of these parameters are a cause for alarm. This water quality data and pollution source information will be useful in identifying water quality problem areas and planning necessary interventions.

AUTHORS' CONTRIBUTIONS

E.S.O. acquired, analysed and interpreted the data. A.M.T. designed the experiment while J.A.A. supervised. GMF and A.M.T. participated in the analysis and interpretation as well as wrote the draft of this manuscript. All authors approve the final manuscript.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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