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Water Quality Index for Evaluating the Quality Status of Ikpoba River in Benin City, Nigeria

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Abstract

The dependence on river water for domestic and drinking purposes is a result of scarcity of potable water. River water is easily polluted through the discharge of effluent and the disposal of solid waste. Evaluation of river water quality status is crucial for public health and environmental sustainability. The study used the National Sanitation Foundation Water Quality Index (NSFWQI) model to assess the quality status of the Ikpoba River in Benin City, Nigeria. Nine physicochemical and microbial parameters were analysed for NSFWQI evaluation following standard procedures. These include dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), phosphate, nitrate, turbidity, temperature, pH, and total coliforms. The NSFWQI values for the samples were within the range of 35.97 to 50.59, which falls within the bad and medium ratings; the mean quality status of the river water is bad. The parameters that did not conform to the limits stipulated by national and international regulatory agencies were majorly BOD, TDS, turbidity, and total coliform. The pollution of the river occurs mainly from anthropogenic activities. The water from the Ikpoba River is unfit for drinking and domestic use; it requires prior treatment before use. Effluents released into the river should be treated to minimum standards set by government regulatory agencies, and disposal of solid wastes and open defecation should be curbed.

1.0. Introduction

Water constitutes an important part of the ecosystem and it is vital for the well-being of plants, animals, and human life [1]. It is also important for economic and environmental processes. Surface water is a major source of fresh water, and streams and rivers constitute part of the limited freshwater catchment available for man's utilisation [2]. Due to water scarcity challenges and lack of access to pipe-borne water in numerous places around the world, many people utilise water from river systems for drinking and domestic purposes [3]. The rivers also serve as sources of water for agricultural and recreational activities, coupled with their role as natural habitats for aquatic organisms [4]. However, the river water system is prone to contamination from numerous sources which can render it unfit for beneficial uses [5]. More so, accumulated levels of the pollutants may impede its ability and capability to undergo self-purification through natural processes.

Anthropogenic activities encompassing the use of fertilisers, herbicides, and pesticides in agricultural ventures, effluents from industrial facilities, and wastewaters from residential areas are major contributors to the pollution of river water. Rivers serve as receiving bodies for effluent discharges and the run-offs from agricultural lands end in rivers [6]. These water streams are often loaded with various hazardous materials, both organic and inorganic, which are increasingly poisoning water and endangering human health, as well as the ecosystem [7]. This brings forward the importance of monitoring water systems to ascertain their health status and suitability for various uses, especially drinking and domestic purposes.

Conventional water quality assessment is mostly done by evaluating the physical, chemical, and microbiological characteristics which are compared to stipulated standards or guidelines. However, water quality and its suitable use can be more easily interpreted with the deployment of modern models such as the Water Quality Index (WQI). The WQI protocols reduce the evaluated data (physicochemical and biological parameters) into a single value for simple interpretation and understanding [8]. One of the WQI models is the National Sanitation Foundation Water Quality Index (NSFWQI) widely utilised for assessing the quality status of rivers, lakes, and coastal waters, as well as groundwater [3, 9, 10]. The NSFWQI model evaluates and uses nine important water parameters to assess water quality; the parameters include dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), phosphate, nitrate, turbidity, temperature, pH, and total coliforms [11]. The NSFWQI parameters are weighted differently based on their importance by assigning values that sum up to one; the integral values assigned to each parameter indicate its environmental significance in water quality assessment [12]. The mathematical computation in the NSFWQI gives values ranging from 0 – 100 which is used to categorise water quality as very bad (0 – 25), bad (26 – 50), moderate (51 – 70), good (71 – 90), and excellent (91 – 100), accordingly [13]. The classification allows for a simple and easy understanding of the water quality for the intended stakeholders.

The Ikpoba River traverses through Benin City in Nigeria, serving as a receiving body for industrial and domestic wastewater [14]. Agricultural run-offs also flow into the river due to its steeply incised valley, which is largely employed for agricultural activities. Conversely, it equally serves as a source of water for residents living along its course due to the inability of the government to provide pipe-borne water to its citizens [15]. Hence, this investigation was carried out to assess the water quality status of the Ikpoba River using the NSFWQI protocol and to ascertain its suitability for domestic usage. Several investigations previously carried out on the Ikpoba River system utilised conventional methods to achieve their purpose; the interpretation of the data poses a challenge to policymakers and the end users of the river water. The Weighted Arithmetic Water Quality Index (WAWQI) method was used to assess the water quality of the Ikpoba reservoir situated in Okhoro in Benin City along the Ikpoba River [16], while another study focused solely on the brewery effluent as the anthropogenic source of pollution of the Ikpoba River [17]. This study took into cognisance numerous anthropogenic contributors to the current quality status of the Ikpoba River and the findings using the NSFWQI protocol are simple to interpret.

2.0. Materials and Method

2.1. Study Area

The Ikpoba River traverses through Benin City in Edo State, Nigeria. It is located between latitude 6.5° N and longitude 5.8° E with its source originating from the Ishan Plateau in the central plains of Edo State, northeast of Benin City [14]. The river is mostly surrounded by steep elevated slopes which have residential areas, industrial facilities, abattoirs, and car wash located along some sections where it flows through the city. Agricultural activities such as farming and aquaculture are carried out along other areas of the slope and the river bank.

2.2. Sample Collection and Preparation

Standard procedures established by the American Public Health Association were followed in carrying out the water sampling [18]. The water samples were collected with three different holding containers (bottles) - 500 mL for the samples for pH, turbidity, TDS, phosphate, and nitrate analysis, 60 mL (brown) for the samples for DO and BOD analysis, and 330 mL for samples for the total coliform analysis. Collection of the water samples was done at three locations - the upstream

(6°20’7” N 5°39’45” E), middle stream (6°20’4” N 5°39’49” E), and downstream (6°20’6” N 5°39’47” E). The middle stream location was at the effluent discharge point of a brewery, while the upstream and downstream were locations before and after the discharge area, respectively. The sampling was carried out in November 2023, December 2023, and January 2024 with a total of 36 samples collected.

2.3. Sample Analyses

2.3.1. Physicochemical analysis

A HANNAH field pH meter was used for the determination of pH *in situ*. The water temperatures were also taken *in situ* using a mercury-in-glass thermometer by immersing the thermometer directly into the water and reading the temperature values as indicated by the rise or fall of the mercury column inside the thermometer. The phosphate and nitrate levels**,** as well as the turbidity, were measured with a HACH DR 2000 spectrophotometer (HACH Company, Colorado, USA). TDS values were determined using a HACH CO150 TDS/Conductivity/Salinity meter. The DO levels were determined using the Azide-modified Winkler’s method. The DO was calculated as follows;

$$DO\ (mg/L) = number\ of\ digits\ on\ digital\ titrator\ x\ digital\ multiplier\ (0.04) \quad (1)$$

The Azide modified Winkler’s procedure was also used to assess the BOD levels of the water samples. The BOD values were calculated as follows;

$$DO_5\ (mg/L) = number\ of\ digits\ on\ digital\ titrator\ x\ digital\ multiplier\ (0.04) \quad (2)$$

$$BOD = initial\ DO - DO\ at\ day\ five\ (DO_5) \quad (3)$$

2.3.2. Microbial analysis

Prior to the commencement of the microbial analysis, an aseptic environment was created by sanitizing the work area with 70% alcohol. Heterotrophic plate count was used for the microbial analysis (total coliform) of water samples. One millilitre (1 mL) of the water samples was poured and plated into the media (Macconkey agar and Nutrient agar). The plates were allowed to solidify and incubated for 24 hours at room temperature. Colonies were counted and identified using conventional biochemical means.

$$Colony\ forming\ unit/mL = \frac{Average\ number\ of\ colonies\ counted}{Aliquot\ volume} \quad (4)$$

The sub-culturing was carried out to get pure culture from a mixed culture. Isolates of the initial culture were transferred to nutrient agar to obtain pure colonies on incubation at 37 °C for 24 hours. The morphological identification was carried out by utilising an alternative to Gram-staining technique (potassium hydroxide and vancomycin susceptibility tests) described by Dash and Payyappilli [19]. Furthermore, a battery of biochemical tests was used to identify the bacterial species by differentiating them based on biochemical and enzymatic activities. The differences in protein and fat metabolism, carbohydrate metabolism, enzyme production, and compound utilisation ability are some factors that aid in bacterial identification [20].

2.3.3. NSFWQI Analysis

The NSFWQI analysis was done using the nine ascribed variables with different weighted mean for each - namely BOD (0.11), DO (0.17), TDS (0.07), temperature (0.10), turbidity (0.08), pH (0.11), phosphate (0.10), nitrate (0.10), and fecal coliforms (0.16) [11]. The assigned integral values sums up to one. Computing the NSFWQI was done following the mathematical expression:

$$NSFWQI = \sum_{i=1}^{n} WiQi \quad (5)$$

Where, Wi = weighting factor, n = number of water quality parameters or sub-indices, Qi = sub-index for ith water quality parameter.
Thereafter, the obtained values were used to categorise the quality status of the water samples, accordingly.

3.0. Results and Discussion

3.1. Physicochemical Parameters Profile of Ikpoba River

The physicochemical parameters results are represented in Figure 1 (a - d) for pH, temperature, turbidity, and TDS, and Figure 2 (a - d) for DO, BOD, phosphate, and nitrate, respectively. The values obtained were compared to the stipulated set guidelines by the national and international standards for drinking and surface waters.

3.2. pH assessment

The variations in pH values for the Ikpoba River are represented in Figure 1a. The pH of the river water ranged from 4.3 to 6.8; the maximum pH value of 6.8 was recorded upstream in November, while the minimum value of 4.3 was obtained at the middle stream for January. The majority (66.67%) of the pH values were between 6.5 - 8.5 specified by the National Environmental Standards and Regulations Enforcement Agency (NESREA) and World Health Organisation (WHO) for drinking [21, 22]. The non-compliant pH values were recorded for November and January at the middle stream and November at the downstream. The low values from the middle stream samples are indicative of the acidic nature of the effluent discharged from the brewery facility. Brewery process wastewater is characteristically acidic due to the infusion of CO_2 in the drinks which forms carbonic acid, coupled with other acidic additives incorporated in the beer [23]. Also, the utilisation of acidic cleaning and sanitation chemical such as phosphoric acid contributes to the acidic nature of the effluent [24]. Low pH conditions pose a threat to aquatic organisms due to its tendency to influence the solubility and toxicity of heavy metals and other chemicals in the water [25].

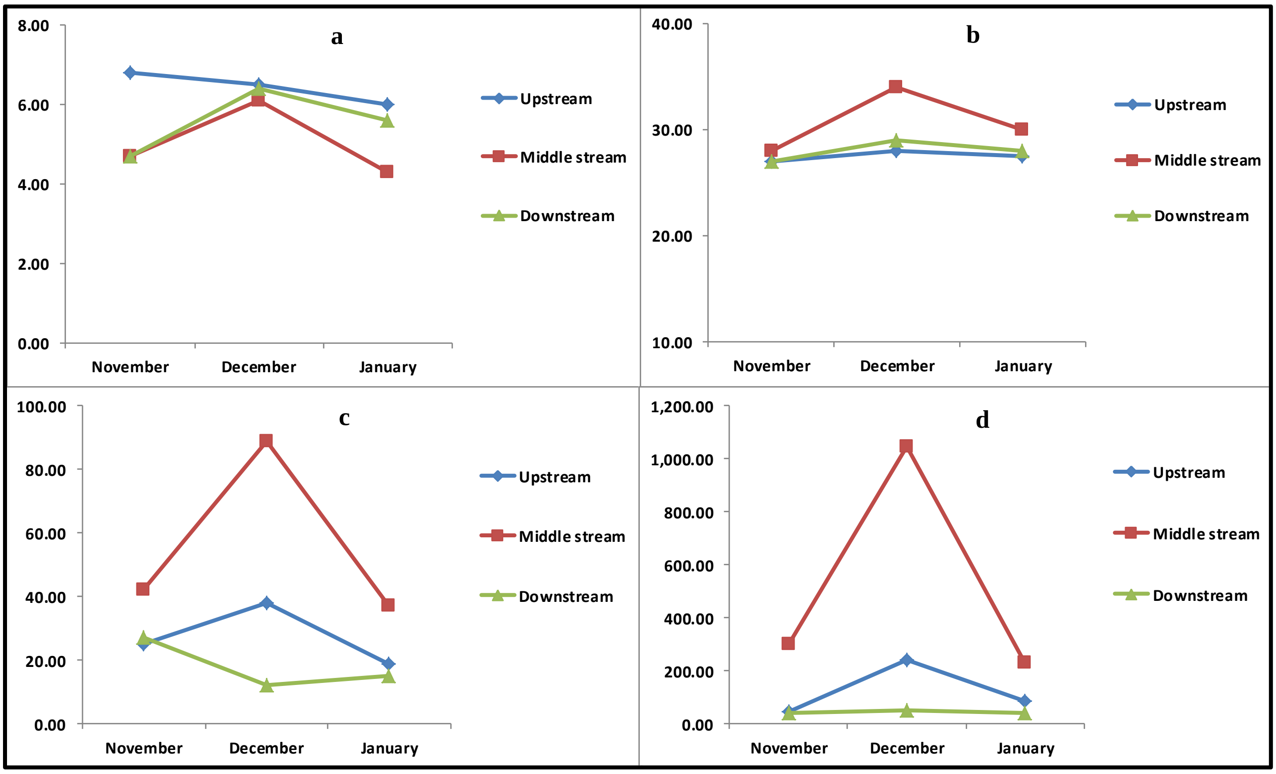

Fig 1: Variation in Ikpoba River water for (a) pH, (b) temperature, (c) turbidity, and (d) TDS

3.3. Temperature assessment

The variations in the river water temperature are represented in Figure 1b. The maximum and minimum of the river water temperatures were 34.0 ^{o}C at the middle stream in December and 27.0 ^{o}C at the upstream and middle stream in November. The middle stream has the highest mean temperature value (30.3 ^{o}C) because that is the point where a brewery discharges its effluent through an underground drainage system directly into the river. The sample for the middle stream in December was collected during effluent discharge, the river water temperature was 34 ^{o}C and the water was hot to the touch, indicating that the effluents are discharged at a higher temperature than that of the river water. Temperature plays an important role in the acceptability of water; cool water is mostly deemed more palatable than warm one. Elevated water temperature may impact negatively on some inorganic chemicals and other constituent contaminants to produce taste in the water. More so, the elevated water temperature can increase the growth of microorganisms with attendant problems related to colour, odour, taste, as well as corrosion [25].

3.4. Turbidity assessment

The turbidity values for the river water are represented in Figure 1c. The turbidity value of the river water was between 12.0 NTU and 89.0 NTU; the turbidity values were higher than the 5 NTU recommended by NESREA and WHO for drinking water, as well as the 10 NTU set for surface water by NESREA. The maximum turbidity value (89.0 NTU) was recorded at the middle stream in December, while the minimum value (12.0 NTU) was for downstream in December. The turbidity value for the middle stream was higher than that of upstream and downstream which may be due to the impact of the effluents discharged from the brewery into the river system. Visually noticeable turbidity negatively affects the acceptability of drinking water [25]. The high turbidity levels of the river water, especially in the middle stream, could be the result of effluent discharges from the brewery facility located in that section of the river [26], while the upstream levels may be influenced by the solid waste dumped in the river from the numerous abattoirs in the locale [27].

3.5. Total dissolved solids assessment

The variations in the levels of TDS values in the river water are represented in Figure 1d. The values ranged between 42.0 mg/L and 1046.0 mg/L; the maximum value of 1046.0 mg/L was observed at the middle stream in December, while the minimum value was at the downstream in November. The TDS values for the middle stream were higher than those of upstream and downstream because it has a higher amount of dissolved solids as a result of effluents discharged from the brewery. The TDS values for upstream and downstream were lower than the 500 mg/L maximum permissible limits stipulated for drinking and surface waters by NESREA and WHO [21, 22]. There are no health concerns associated with the level of TDS in drinking water. However, elevated TDS levels in drinking water may be objectionable to consumers; it can affect the taste of the drinking water [27].

3.6. Dissolved oxygen assessment

The variations in the levels of DO in the river water are represented in Figure 2a. The DO levels ranged from 2.5 mg/L to 11.8 mg/L; the maximum DO level of 11.8 mg/L was obtained downstream for December, while the minimum value of 2.5 mg/L was recorded upstream in November. The DO values for all locations in November were below the guidelines set by NESREA and WHO for drinking water and surface water. The values recorded in December and January were compliant with the set guidelines for surface water, except for the 4.0 mg/L DO level obtained upstream in January. DO measurements are used to ascertain the quality and natural contamination in surface water systems [28].

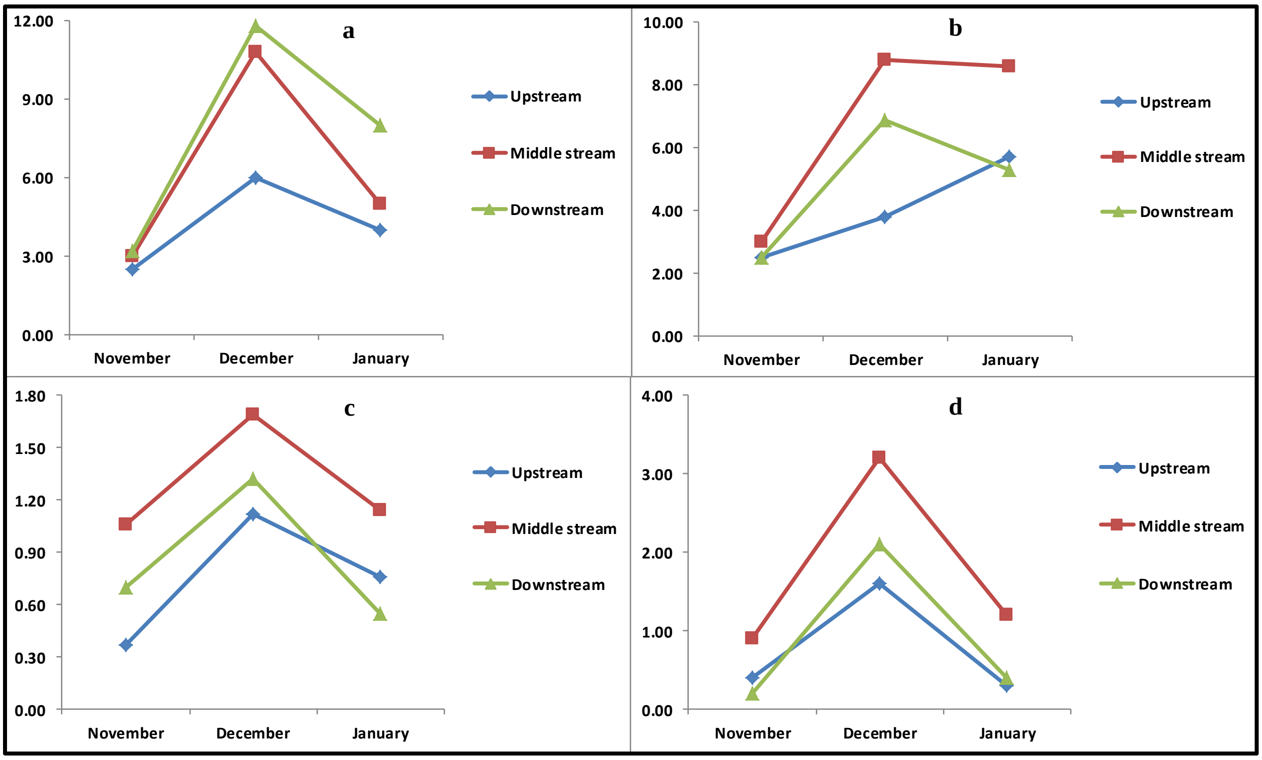

Fig 2: Variation in Ikpoba River water for (a) DO, (b) BOD, (c) phosphate, and (d) nitrate

3.7. Biochemical oxygen demand assessment

The variations in values of BOD in the river water are represented in Figure 2b. The maximum BOD value was 8.8 mg/L downstream in December, while 2.5 mg/L was recorded as the minimum value at the upstream and downstream locations in November. The BOD levels for upstream and downstream are lower than the NESREA standard for effluent discharges, irrigation, and reuse standards. For the middle stream, the BOD levels for the three sampled locations were higher than the maximum permissible limit of 5.0 mg/L set by NESREA for fisheries and recreation quality criteria standards [21]. BOD is used to evaluate the self-purification capacity of rivers and it is a critical parameter for effluent quality assessment before discharge into water bodies [29].

3.8. Phosphate assessment

The variations in phosphate levels of the river water are represented in Figure 2c. The recorded levels (0.37 mg/L - 1.69 mg/L) were above the NESREA maximum permissible limit of 0.1 mg/L for drinking and surface waters. The highest phosphate levels were recorded at the middle stream location where the river receives effluent from the brewery industry which routinely uses phosphate-based cleansers for cleaning and sanitizing their bottling equipment [30].

Excessive phosphate in surface water systems comes with its nuisance as it is one of the contributing nutrients responsible for eutrophication. Also, numerous issues with water quality have resulted from this, such as higher purification costs, interference with impoundments' recreational and conservation value, livestock losses, and potential sub-lethal effects of algae toxins on people who drink eutrophic water [1].

3.9. Nitrate assessment

The variation in nitrate levels of the Ikpoba River water is represented in Figure 2d. The maximum concentration was 3.2 mg/L for the middle stream in December, while the minimum concentration was 0.2 mg/L for downstream in November. The recorded concentration range of 0.2 mg/L - 3.2 mg/L was within the NESREA and WHO guidelines (10 mg/L) for both drinking water and surface water. A high nitrate level in surface water is a major contributor to eutrophication, impacting negatively on the quality of the surface water. It can cause hypoxia - low levels of dissolved oxygen; and exert a toxic effect on warm-blooded organisms at concentrations > 10 mg/L. Typically, the natural concentration of nitrate in surface water is < 1 mg/L; however, nitrate levels in wastewater treatment plant discharges can range up to 30 mg/L [31]. Hence, the higher nitrate levels observed at the middle stream may be influenced by the effluent discharged from the brewery facility.

3.10. Microbial Profile of Ikpoba River

The presence of coliform bacteria is an indication of faecal contamination majorly from the intestines of warm-blooded animals, including humans. The total coliform counts of the three sampling locations in Ikpoba River for November, December, and January are represented in Figure 3. The average coliform counts for the upstream, middle stream, and downstream were 29,513 CFU/100 mL, 3162 CFU/100 mL, and 417 CFU/100 mL, respectively. The maximum counts were recorded at the upstream location of the river, while the least counts were observed for the downstream section. The values for the total coliform count were higher than the NESREA and WHO guidelines for drinking and surface waters. The bacteria identified were *Escherichia coli*, *Bacillus mycoides*, *Enterobacter aerogenes*, and *Serratia marcescens* (Table 1). The *E. coli* and *E. aerogenes* are indicative of faecal contamination [4], and they could pose severe public health implications such as gastroenteritis and haemolytic uremic syndrome [15]. More so, *E. coli* can induce hemorrhagic colitis and kidney failure when ingested [32].

The high coliform counts observed at the upstream location are largely attributed to the meat processing facilities (abattoirs) located along the bank of the river in that section. These abattoirs are not equipped with wastewater treatment facilities; hence, the untreated wastewater and other intestinal waste matter end up in the river system. The high feacal load of the Ikpoba River renders the water unsuitable for domestic and drinking purposes.

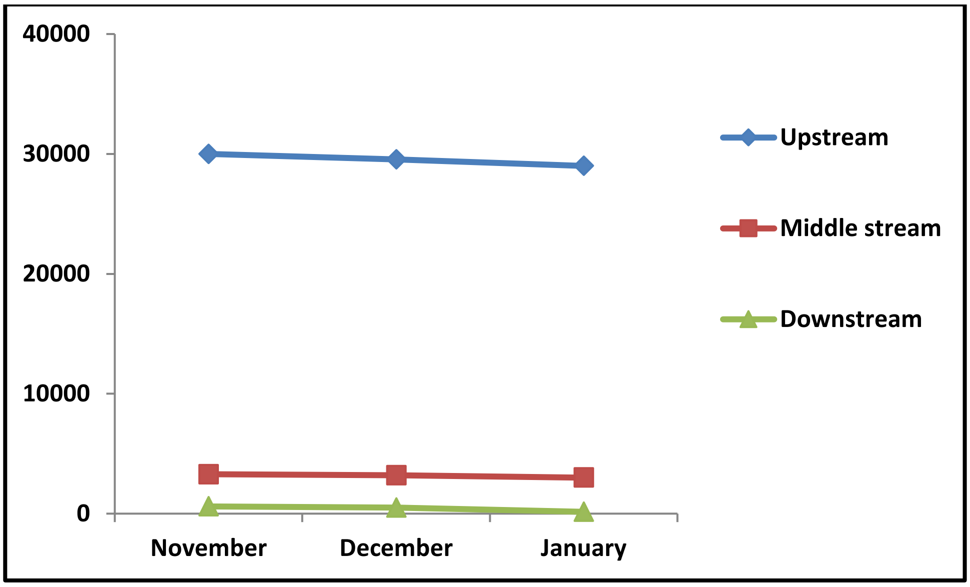

Figure 3: Variation in the total coliform count of sampled locations

Table 1: Morphological and biochemical characterization of bacterial isolates

Morphological				
Elevation	Flat	Flat	Flat	Raised
Margin	Undulate	coarse	Undulate	Entire
Colour	Cream	milk white	Cream	Cream
Shape	Irregular	concave	Irregular	Circular
Size	Large	large	Large	Medium
Gr. diff. agar	EMB	BCA	EMB	EMB
Colour	green	Straw	pink	opaque
Staining				
Gram stain	-	+	-	-
cell type	Rod	Rod	Rod	rod
Arrangement	disperse	disperse	disperse	disperse
Colour	pink	purple	pink	pink
Spore staining	-	+	-	-
Biochemical				
KOH String Test	+	-	+	+
Catalase	+	+	+	+
Indole	+	-	-	-
Citrate	-	-	+	+
Oxidase	-	-	-	-
Motility	+	+	+	+
Urease	-	-	-	-
Glucose	+	+	+	+
Sucrose	-	-	+	+
Lactose	+	-	+	+
Mannitol	-	-	-	+
Gas formation	+	-	-	-
H2S formation	-	-	-	-

TSI (Slant/Butt) reaction	A/AG	K/A	A/A(K*)G*	**K/A (*A/A)**
Esculin Hydrolysis	-	+	+	-
Identity	*E. coli*	*Bacillus mycoides*	*Enterobacter aerogenes*	*Serratia marcescens*

3.11. NSFWQI assessment

The result from the NSFWQI assessment of the three locations in the Ikpoba River showed that the downstream recorded the highest numerical value of 50.59, categorised as "moderate" water quality. The middle stream had a lower value of 35.97 compared to the upstream value of 43.2. The river water quality based on the numerical mean of the NSFWQI values was determined to be 43.25 in the months studied. Both the upstream and the middle streams had "poor" water quality according to the NSFWQI rating, while the overall river water quality was determined to be within the "poor" quality range for the months studied. The pollution of the river is a result of effluent release from activities like industrial processes, meat processing, car-washing, washing of rugs, laundry services, and vehicle servicing. Wastewater from restaurants and residential buildings was also identified contributor.

Factors that can affect surface water quality are effluent discharge and disposal of waste into rivers [8]. The high BOD denotes high organic matter pollution of the river due to the untreated discharge of municipal and domestic waste. This makes the water body unsuitable for aquaculture [5]. Particularly, the numerous abattoirs located in the upstream location are responsible for the high feacal load and organic matter content resulting in low-level DO. The poor quality status of the Ikpoba River and its vulnerability to pollution in the middle stream is induced by the non-compliant effluent discharged into the river from the brewery facility in that area [17]. The discharged brewery effluent stream impacted negatively on the aesthetic quality of the Ikpoba River at the point of discharge [4].

The assessment of the water quality from Mojen River using the NSFWQI index indicated that the quality status was medium, as a result of sewage discharge from residential areas around the river [33]. According to Dehghani, et al. [34], the numerical rate of the NSFWQI index, of the Ghohrood River of Kashan varied from average to good and the source of pollution was from the dam and animal waste. Comparing the NSFWQI value of the Mojen and Ghorood Rivers with that of the Ikpoba River, it can be posited that the poor water quality is a result of anthropogenic activities around it. In the analysis of the suitability of fifteen rivers within Warri metropolises using the WQI, Godwin and Oborakpororo [27], deduced that the river systems were unfit for human consumption. The major anthropogenic contributors were the meat processing facilities located along the water course, the disposal of untreated wastewater, and the dumping of solid wastes into the surface water. River Ona in the Oluyole Industrial Estate of Ibadan was heavily polluted from the numerous domestic and industrial activities in the area and was considered unfit for drinking and domestic purposes [35]. Studies on the Ruvu River showed that the decline in the water quality was mainly due to untreated residential wastewater and industrial effluent that is discharged into the river, and improper solid waste management [36]. Overall, anthropogenic activities in and around surface water systems are largely responsible for their pollution.

Over time, abattoir operators conveniently locate their facilities close to surface waters. They utilise the water source for their various processes and also channel their wastewater and solid wastes into it. This practice has led to the deterioration of such surface water systems, prevailing more in the immediate area of discharge. The discharge of untreated wastewater and solid waste by abattoirs needs a holistic approach from all stakeholders to tackle the challenge. Importantly, the environmental regulatory body in the country must formulate a policy framework targeted at small to medium-scale meat processing facilities which are the major culprits in this case. Modalities on

how to collect, treat, and dispose of the wastes they generate, as well as, the monitoring for compliance should be properly outlined and enforced for a sustainable environment.
Industrial facilities tend to be also located close to surface water systems, where possible; and most often, the dual purpose of access to water and discharge of effluent is exploited. Although industrial facilities are mandated to have effluent treatment plants by the nation's environmental regulatory body, many industries still lack this facility which leads to the unabated discharge of untreated effluents. In industries with effluent treatment plants, the facilities do not function optimally due to operational challenges [37]. More so, the lapses in the monitoring and enforcement role of the agency overseeing environmental issues in the country contribute to industries not complying fully. Generally, more environmental sustainability consciousness is needed from the government, corporate organisations, and citizens to align with the Sustainable Development Goals (SDGs) focusing on clean water and sanitation (goal 6) and good health and well-being (goal 3).

4.0. Conclusion

The water quality status of Ikpoba River in Benin City was assessed in this study using the NSFWQI protocol. The results showed that most of the physicochemical parameters and microbial evaluations were outside the stipulated guidelines set by national and international regulatory bodies. The river water quality based on the numerical mean of the NSFWQI values was determined to be within the "poor" quality range for the months studied. Hence, the Ikpoba River water at these locations is unsuitable for direct drinking and domestic usage. The pollution of the river occurs mainly from anthropogenic activities. The continuous pollution of the river may lead to an overload of pollutants inhibiting the ability of the river to self-purify. Industrial effluents released into the river should be treated to attain the minimum quality threshold as stipulated by regulatory agencies. Measures to collect and treat the wastewater from the abattoirs located along the river bank should implemented by all concerned stakeholders.

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