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ORIGINAL ARTICLE

Evaluation of the physicochemical properties and bacterial loads of selected rivers in Ondo State, Nigeria

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ABSTRACT

Background and Objectives: Water is crucial to human existence but may be contaminated with microorganisms, thus making it unfit for consumption. This study aimed to evaluate the physicochemical properties and bacterial loads of selected river waters in Ondo State, Nigeria.

Materials and Methods: Ten major rivers were sampled between April and August, 2021. The pH, temperature, total alkalinity, colour, turbidity, electrical conductivity, dissolved oxygen, ammonium, aluminium, organic matters, nitrate levels including the microbial loads were determined according to standard procedures. Confirmation of identified isolates was achieved by API 20E and API 20NE.

Results: The turbidity, colour, conductivity, ammonium, and aluminium ranged from 4.3 to 15.2 NTU, 4 to 20 NTU, 123.5 to 580.2 mgL^{-1}, 0 to 3.5 mgL^{-1}, and 0.05 to 1.7, respectively. Most physicochemical parameters showed no significant differences from the WHO permissible limits for drinking water ($p > 0.05$). The total viable bacterial count in the rivers ranged from 1.5×10^5 to 6.3×10^5 $CFUmL^{-1}$, while the total coliform count ranged from 1.3×10^3 to 4.8×10^3 $CFUmL^{-1}$. The predominant bacteria were *Escherichia coli* and *Pseudomonas aeruginosa.*

Conclusion: This study revealed that the physiochemical properties of the waters were majorly within the WHO permissible standards but with significantly higher bacterial loads.

Keywords: Aerobic bacteria; Physicochemical concept; Environmental pollution; River; Water body; World health organization

INTRODUCTION

Water is one of the most abundant and important compounds in the ecosystem. All the organisms that are living on earth need water for survival and growth. The pollution of water causes diseases which result to the death of million people. Safe drinking water is one of the natural resources and a basic need for the survival and development of all humans (1, 2). Often, the source and potability of water supply are reflected on the health conditions of communities as bacteriological contamination of water is the prima-

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ry cause of disease outbreaks in many communities particularly in many developing countries (3). Water can be grouped into surface water (such as oceans, rivers, lakes, reservoirs, lagoons, streams), ground water (which is regarded as a purer source of water than any type of surface water) and then rain water (which is as a result of the clouds condensing and precipitating).

Surface water usually contains components that must be eliminated before it could be considered potable while groundwater is expected to be contaminant-free. Numerous places, worldwide receive their water sources from surface waters, such as rain, creeks, rivers, lakes, etc and therefore, it is essential to ensure that these surface sources of water are contaminants free. Rivers provide a variety of services for human populations, including water for drinking and irrigation, recreational opportunities, and habitat for economically important fisheries (4). The increasing problem of river ecosystem pollution has necessitated the monitoring of water quality. Rivers are a major source of water for different purposes for highly populated residential areas. A river's flow is affected by surface run-off, direct precipitation; interflow, and water table discharge. The physicochemical and biological components of the various flows influence the quality of the river and other surface waters. The quality of the river water is also influenced by the atmospheric inputs, climatic conditions, lithology of the basin, and anthropogenic inputs (5, 6).

Rivers play a major role in the accumulation and carrying off of municipal and industrial wastewater and runoff from agricultural land. The assimilation of waste constitutes of constant polluting non- point sources while runoff of municipal and industrial wastewater is a seasonal phenomenon (7). The rapid development in agriculture, mining, urbanization, and industrialization activities has led to an increase in surface water (including rivers and streams) contamination, depositing hazardous wastes and wastewater in the water bodies. It was reported that in South Africa, over 15% of rural dwellers depend on polluted river waters for their domestic needs; 70% of people in Sudan get their water supply from surface waters, which in most cases are polluted by agricultural chemicals and industrial effluents (4). About 47 million Nigerians depend on either polluted surface waters or wells for their domestic activities (8).

Farmers are the predominant people residing close to rivers and they use poultry droppings as well as chemical fertilizers to enrich their farmlands; these constitute pollutants which drain into the river through run-offs. All the domestic and industrial wastes as well as sewage from surrounding areas are washed into rivers during runoff (9). Also, the topography of the city slopes into the river and drainage channels are emptied into the river. This situation may eventually lead to pollution of the river which might have dire consequences on the ecosystem. There are temporal and spatial variations in the biological and physicochemical properties of rivers but these depends on the nature and amount of effluents received at different points in time (10).

There is paucity of information on the physicochemical and bacteriological qualities of the rivers in these studied rivers except a study on the microbial and physicochemical qualities of river Owena water reported by Ayo and Arotupin (11). The aim of this study was to determine the physicochemical and bacteriological qualities of ten major rivers in Ondo State, Nigeria.

MATERIALS AND METHODS

Study area and design. Ondo State is one of the Nigerian states situated in southwest geo-political zone of the country. The population of the state is currently estimated at 5,372,777 including both children and adults. The state covers 15,049 km^2 with population density presently pegged at 410.3/km^3 (12). Ten major rivers were identified within the State for this investigation and these include Itanla, Owena, Ofosu, NCI, Ile-Oluji, Igbado, Omolore, Ajue, Oka and Laje rivers. This is a cross-sectional study, from April to August 2021, designed to determine and compare the physicochemical properties and the bacterial loads in the rivers with WHO permissible limits for domestic waters.

Determination of the physicochemical properties of river water samples. The river water samples considered to be representatives of the rivers in Ondo State, Nigeria were selected for the study. One sampling point was selected for each of the rivers based on ease of accessibility while each river was sampled three times. Water samples for laboratory physicochemical analyses were collected mid-stream at depths of 20-50 cm into clean one-litre sterilized glass containers. These containers were tightly sealed and labelled on the field. The electrical conductivity

(EC) and pH were measured *in situ* where possible. The dissolved oxygen (DO) was determined by titration (Winkler) method in the laboratory. The Whitman PHA 260 pH-meter was used to measure the water temperatures and pH. The total alkalinity, colour, turbidity, ammonium, aluminium, organic matters, and nitrate levels were measured following standard methods (13).

Bacteriological analysis of river water samples. A 250-mL capacity of thoroughly washed and heat-sterilized sampling glass bottles were used for the collection of river water samples in same manner employed for the collection of water samples while determining physicochemical parameters of the river waters. The collected samples were placed in an ice-packed cooler, transported immediately to the laboratory and preserved in refrigerator at 4°C until they were analysed. Water samples were serially diluted to obtain dilution factors of up to 10^{-5}. One (1) mL of 10^2 and 10^4 dilution factors was inoculated on various agar media using the spread plate technique. The nutrient agar and MacConkey agar were employed for the cultivation and enumeration of total viable bacteria and coliforms, respectively. Mannitol salt agar medium was used for the isolation of *Staphylococcus aureus*, while *Salmonella-Shigella* agar was used for isolation of *Salmonella* sp. The discrete colonies were sub-cultured to obtain pure isolates. Bacterial isolates were characterized based on cultural (colonial), microscopic and biochemical methods with reference to standard manuals. Biochemical tests carried out included catalase test, coagulase test, oxidase test, sugar fermentation, hydrogen sulfide production test, urease test, IMViC test, indole test, and citrate utilization test. The API 20E and API 20NE were used for the confirmation of the family Enterobacteriaceae and non-Enterobacteriaceae, respectively (2).

Statistical analysis. The data obtained from the physicochemical parameters and bacteriological analysis were compared with WHO standards for drinking water using the one-sample t-test. IBM SPSS Statistics Data Editor Version 25 was employed for the analysis.

RESULTS

Physicochemical analysis of the river waters. Table 1 shows the physicochemical properties of selected rivers in Ondo city, Nigeria. The pH of the river water samples investigated ranged from 6.6 to 7.1. The measurement of turbidity revealed a range of 4.3 to 15.2 NTU as found in Omolore river and Ajue river respectively while the values for colour ranged from 4 to 20 NTU as encountered in Igbado and Ajue respectively. The values obtained for the conductivity of the water ranged from 123.5 to 580.2 mgL^{-1} as obtained from Oka river and Igbado river respectively; ammonium content ranged from 0 to 3.5 mgL^{-1} as in Owena river and Ajue river respectively; aluminium ranged from 0.05 to 1.7 as found in Igbado river and Ile-Oluji river, respectively; dissolved organic matter ranged from 0.09 to 2.6 mgL^{-1} as encountered in Ile-Oluji and Ajue river respectively; the total alkalinity ranged from 186.5 to 440 mg $CaCO_3$ L^{-1} as in Laje river and Ajue river respectively, nitrate level of the water ranged from 15 to 55 mgL^{-1} as found in Owena river and Ajue river respectively, while the dissolved oxygen ranged from 3.8 to 7.5 as encountered in Owena river and Omolore river, respectively.

Bacteriological analysis. The bacterial loads of the rivers investigated in this study are given in Table 2. The total viable bacterial count (TVBC) in the rivers ranged from 1.5×10^5 to 6.3×10^5 $CFUmL^{-1}$ as found in Laje river and NCI river respectively, while the total coliform count (TCC) ranged from 1.3×10^3 to 4.8×10^3 $CFUmL^{-1}$ as in Laje river and Omolore river respectively. A total of 283 bacterial isolates were obtained from the different river water samples and these were characterized into eight bacterial species. These bacterial species were *S. aureus*, *Pseudomonas aeruginosa*, *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella pneumoniae*, *Salmonella enterica*, *Citrobacter freundii* and *Shigella flexneri*. The percentage occurrence of bacteria isolated from the various river waters is shown in Fig. 1. *E. coli* had the highest percentage occurrence of 23.68% in the river waters, followed by *P. aeruginosa* (21.2%), *S. aureus* (19.08%), *K. pneumoniae* (14.84%), *C. freundii* (8.48%); *E. aerogenes* (6.36%), *Salmonella enterica* (4.24%) and *Shigella flexneri* (2.12%).

The data obtained from the physicochemical parameters and bacteriological analyses of the river waters were compared with WHO standards for drinking water (Table 3). Although there variations in values of the physicochemical parameters recorded but there were no significant differences between the pH, co-

Table 1. Physicochemical properties of selected surface water in Ondo State, Nigeria

Sample	River Location	pH	Temperature (°C)	Turbidity (NTU)	Colour (TCU)	Electrical conductivity (mg/L)	Ammonium (mg/L)	Aluminium (mg/L)	Organic matters (mg/L)	Alkalinity (mg $CaCO_3$ L^{-1})	Nitrates (mg/L)	Dissolved oxygen (mg/L)
WHO (1996)	Guideline	6.5-8.5	24	<5	<15	<1000	<1.5	<0.2	<0.5	500	<50	>3.0
S1	Itanla	7.1	25	4.5	12	224.5	1.2	0.1	0.1	219.5	24	4.6
S2	Owena	7.0	25	5.3	7	128.8	0	0.7	0.4	195.7	15	3.8
S3	Ofosu	6.9	26	7.1	10	201.9	5	0.1	1.7	389	27	5.6
S4	NCI	6.7	25	5.9	5	107.7	1	0.2	0.1	241.5	32	7.1
S5	Ile-Oluji	6.8	25	12	17	437.5	2.5	1.5	0.09	400.5	43	5.6
S6	Igbado	7.1	25	7.7	4	580.2	1.1	0.05	1.9	122.1	31	6.6
S7	Omolore	6.6	25	4.3	6	550.6	0.7	0.09	0.4	230	39	7.5
S8	Ajue	6.7	26	15.2	20	180.9	3.5	1.1	2.6	440	55	4.9
S9	Oka	7.0	25	5.7	8	123.5	1.4	0.06	0.3	200.5	42	7.3
S10	Laje	6.9		6.2	7.5	228	0.9	0.09	0.2	186.5	33	6.7

Values represent the mean of the three replicate samples.

Table 2. The microbial loads of selected rivers in Ondo State, Nigeria

Water Sample	River location	Total viable bacterial count (TVBC) × 10^5 (CFU/mL)	Total coliform count (TCC) × 10^3 (CFU/mL)
S1	Itanla River	4.7	2.3
S2	Owena River	4.3	3.8
S3	Ofosu River	4.4	1.5
S4	NCI River	6.3	1.7
S5	Ile-Oluji River	5.2	2.1
S6	Igbado River	3.1	1.2
S7	Omolore River	1.9	4.8
S8	Ajue River	5.4	4.2
S9	Oka River	2.1	4.1
S10	Laje River	1.5	1.3

Values represent the mean of the three replicate samples.

lour, temperature, electrical conductivity, alkalinity, nitrate content, turbidity, aluminium, dissolved oxygen, organic matters and the WHO permissible standards for drinking water. In the contrary, there were statistical differences between ammonium, total viable bacteria count, total coliform count and the WHO permissible standards (Table 3).

DISCUSSION

Information about physicochemical and bacteriological qualities of the major rivers in Ondo State, Nigeria was scanty prior to this study. Ayo and Arotupin (11) earlier studied one of the rivers and reported a total of ten bacterial species from Owena river. They reported a pH of water ranging from 6.72 to 7.52 ± 0.01, dissolved oxygen from 5.95 to 7.63 ± 0.01 mg/l, while biological oxygen demand ranged from 3.20 to 11.47 ± 0.01 mg/L. The physicochemical properties of the river waters sampled during the study period were summarized in Table 1. The pH of the water ranged from 6.6 to 7.1. All the river waters were within the acceptable range for domestic water as indicated by WHO Guidelines for Drinking Water Quality (14). This result deviates from the report of Gintamo et al. (15) who reported the pH range of water from 5.5 to 8.0 in the dry season and a range of 6.4 to 7.9 in the wet season. A pH value greater than 7.0 is vital for the growth and reproduction for the

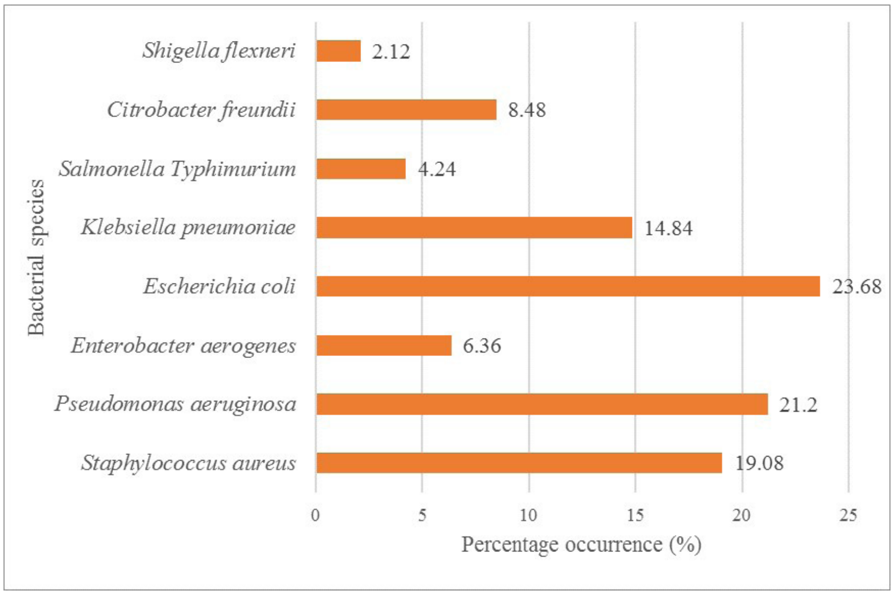

Fig. 1. Percentage occurrence of bacterial species isolated from river waters in Ondo State, Nigeria

Table 3. Statistical differences between the WHO standard values and the parametric values of river water samples

	One-sample t test					
	T	**df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Difference Lower**	**Interval of the Upper**
pH	-2.167	9	.058[b]	-.120	-.25	.01
Temperature (◦C)	.557	9	.591[b]	.100	-.31	.51
Turbidity (NTU)	2.150	9	.060[b]	2.390	-.12	4.90
Colour (TCU)	-.211	9	.838[b]	-.350	-4.11	3.41
Electrical conductivity (mg/L)	-2.190	9	.056[b]	-123.640	-251.33	4.05
Ammonium (mg/L)	-17.336	9	.000[a]	-8.2700	-9.349	-7.191
Aluminium (mg/L)	1.209	9	.258[b]	.1990	-.173	.571
Organic matters (mg/L)	.956	9	.364[b]	.2790	-.381	.939
Alkalinity (mg $CaCO_3$ L^{-1})	-.423	9	.681[b]	-15.8818	-99.510	67.747
Nitrates (mg/L)	1.155	9	.278[b]	4.100	-3.93	12.13
Dissolved oxygen (mg/L)	-.075	9	.942[b]	-.030	-.93	.87
Total viable bacterial count (CFU/100 mL)		9	.000[a]	353181.818	222032.50	484331.13
Total coliform count (CFU/mL)		9	.000[a]	2454.545	1421.90	3487.19

The p values with superscript [a] indicate significant differences from the WHO standards for drinking water while p values with superscript [b] show no significant difference.

majority of mesophilic pathogenic bacteria involved in the biodegradation of organic matter dissolved in water. Total alkalinity ranged from 186.5 to 440 mg $CaCO_3$ L^{-1}. The values of the total alkalinity in the rivers investigated fell within the acceptable limit for domestic water (Table 1). This depicts that the river waters sampled had stable pH. Total alkalinity is an estimate of the ability of water to resist change in pH when an acid is introduced (7). The alkalinity of water is known to be primarily dependent on CO_3, HCO_3 and OH ions, it is therefore substantial that such ions were less in the investigated rivers. The alkalinity of these river waters was consistent with the report of Gambo et al. (16) which was also in the range of WHO recommended standards. However, Joshi et al. (17) who investigated river ganga, India reported values that deviated from the findings of this study.

The dissolved oxygen (DO) of the sampled water ranged from 3.8 to 7.5 mg/L. This concentration was higher than the minimum concentration of 3.0 mg/L required for the protection of aquatic lives. The concentrations of DO measured in the river waters investigated fell within the range for excellent quality potable water for domestic supply and recreational purposes. Water meant for domestic and recreational purposes should not contain DO concentration less than 3.0 mg L^{-1} (14). The dissolved oxygen levels in waters above the 5.0 mg L^{-1} concentrations suggest their potentials of supporting fish life and aerobic organisms.

Turbidity levels revealed a range of 4.3 to 15.2 NTU. In most of the river waters investigated, turbidity levels were above the acceptable maximum limit for drinking water (Table 1). Water with high turbidity is normally considered to have a high load of microorganisms, and elevated turbidity levels may make the water difficult to get disinfected. The river waters have high turbidity values and this could be attributed to soil erosion and runoff, which are usually high during the high rainfall months. Heavy rainfall results into flooding, thus washing silt, nutrients, and household wastes into the water bodies, thereby, fluctuating the turbidity levels of the water bodies (7).

The values for water colour ranged from 4 to 20 NTU. Most of the water sources investigated had water colour above the acceptable limit for drinking water (Table 1). The variation in water colour of the water bodies investigated could be linked with the variation in the amount of dissolved and colloidal humic substances. The high level of water colour in the sources is significant as it increases the cost of water treatment. Electrical conductivities (ECs) of the sampled river waters ranged from 123.5 to 580.2 mgL^{-1}. The conductivity values of the most of the river waters investigated fell within the WHO acceptable range for domestic water. This could be associated with the high rainfall during the study period. Amin et al. (18) reported that conductivity was high during low rainfall months while low conductivity values were obtained during the high rainfall months.

The TVBC in the rivers investigated in this study ranged from 1.5×10^5 to 6.3×10^5 $CFUmL^{-1}$ while the TCC ranged from 1.3×10^3 to 4.8×10^3 $CFUmL^{-1}$. The notion of coliforms as bacterial indicators of microbial quality of water is primarily based on the fact that coliforms are found in excessive numbers in the faeces of human and other warm-blooded animals. Thus, their presence in river waters suggests contamination with matter of faecal origin (19). The bacteria isolated were *S. aureus*, *P. aeruginosa*, *E. aerogenes*, *E. coli*, *K. pneumoniae*, *S. enterica*, *C. freundii* and *S. flexneri*. *E. coli* had the highest percentage occurrence of 23.68% in the river waters, followed by *P. aeruginosa* (21.2%), *S. aureus* (19.08%), *K. pneumoniae* (14.84%), *Citrobacter freundii* (8.48%); *E. aerogenes* (6.36%), *Salmonella enterica* (4.24%) and *S. flexneri* (2.12%) (Fig. 1).

All ten river waters analyzed contained markers of faecal pollution such as total coliforms, and thermotolerant coliforms (*E. coli*, *K. pneumoniae*, *C. freundii* and *E. aerogenes*) (Table 2) and the presence of these organisms were indicative of the fact that the river waters were unfit for human consumption and should undergo thorough treatment before drinking. This is consistent with the reports of Agwu and Avoaja (20) in Aba, Abia State; Nduka et al. (21) in Warri, Delta State; and Cabral et al. (22). Similar microorganisms were also earlier reported by Egberongbe et al. (23) in their study of stream water for domestic use in Ijebu North Local Government, Ogun State, Nigeria.

The organisms encountered in this study are of public health importance. *E. coli* is conventionally inhabitant of the intestines of most man and animals. It causes bacterial intestinal and extra-intestinal infections including septicaemia, diarrhoea, urinary tract infections, and neonatal meningitis in man and livestock (24). It is often linked with multiple antimicrobial resistances (25), and among bacteria isolated from animal foods, such as pigs, cattle, and poultry (26).

P. aeruginosa inhabits water, soil, plants, and animals. It easily causes infections in immune-compromised but hardly establish infections in healthy individuals (27, 28). It has been labelled among the top-ten hospital 'superbugs' as a result of its widespread antimicrobial-resistant strains leading to life-threatening health conditions (29, 30). *C. freundii* occurs mostly in water, food, soil and sewage. The organism is also associated with non-potable water that normally undergo poor chlorination process (31).

Infections caused by *E. aerogenes* include bacteremia, endocarditis, septic arthritis, skin and soft-tissue infections, lower respiratory tract infections, urinary tract infections (UTIs), osteomyelitis, CNS infections, intra-abdominal infections, and ophthalmic infections (32). *S. aureus* is a normal flora of humans. It causes a wide range of infections such as endocarditis and septicaemia (33). Food poisoning by the staphylococcal toxin is characterised by diarrhoea, nausea, abdominal cramping, and vomiting within 24 h of ingestion (34). *K. pneumoniae* could be found in surface waters, soil, plants, and intestines of man and animals. It is an opportunistic pathogen as it causes infections such as pneumonia, UTIs, and bloodstream infections, in immunocompromised individuals. *K. pneumoniae* infections are a threat to public health because of its potential acquisition of multidrug-resistant genes (35). *S. enterica* is transmitted through faecal-oral route (36). *Shi- gella* causes an infection known as shigellosis. Most infected individuals develop fever, diarrhoea, and stomach cramps, but often recover without chemotherapeutic interventions (37).

CONCLUSION

This study revealed that the river waters investigated are mostly unfit for domestic purposes and were contaminated with potential pathogenic microbial species. Some physicochemical properties and bacterial loads in the waters deviated significantly from the recommended WHO guidelines for domestic waters. The implications are that there is lack of safe and sanitary water supply in certain populations in Nigeria, hence the reason the country, just like many Sub-Saharan African population suffer markedly from water-borne infections. It is, therefore, recommended that the water from these sources be treated to suit domestic purposes.

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