

Assessment of the Microbial and Physicochemical Quality of Water: Evidence from Selected Groundwater Sources from The Coastal Region of Ondo State, Nigeria.

Ikuesan Felix Adeleke¹ * and Ediagbonya Thompson Faraday²

¹Department of Biological Sciences,
Olusegun Agagu University of Science and Technology,
Okitipupa,
Nigeria

²Department of Chemical Sciences,
Olusegun Agagu University of Science and Technology,
Okitipupa,
Nigeria

Email: fa.ikuesan@oaustech.edu.ng

Abstract

The coastal area of Nigeria frequently experiences pollution of water due to various human activities that may compromise the quality of underground water. This study evaluated the microbial contamination and quality indicators of groundwater in the coastal environment of Ondo State, Nigeria. Nine underground water samples were collected from the study area and assayed using conventional microbiological techniques coupled with standard physical and chemical analytical procedures. Results revealed that all the samples had total viable bacterial counts, fungal counts and coliform counts which ranged from 61.25 to 85.32 CFU/100 mL, 10.00 to 35.32 SFU/100 mL and 6 – 24 MPN/100 mL respectively, which were higher than the set WHO limit. Results also revealed that the samples from Irele and Ese- Odo Local Governments Areas had acidic pH in the range of 4.20 -5.21 considered to be below the WHO permissible limit whereas only one of three samples from Ilaje Local Government had acidic pH of 5.23. The concentrations of the heavy metals varied among the samples with manganese (0.183-0.311) mg/L exceeding the 0.08 mg/L prescribed by the WHO. The high microbial load, acidic pH of 4.20 -5.23 in 77.78 % of samples and elevated amount of certain metals suggest the need for water quality monitoring and intervention by government and oil multinationals operating in the area noting that adequate supply of safe - drinking water will improve human health and reduce the burden of waterborne diseases.

Keywords: Coastal area, Drinking water, Microbial contamination, Underground water, Water Quality Index,

INTRODUCTION

Water is one of the most essential natural resources required by all life forms for all life processes across ecosystem and human survival on the earth. Water possesses unique properties different from most natural resource (Divya and Mahadeva, 2013) and nature provides no alternative to water in many of its daily uses and life without water dries up and dies. Among our daily needs for water is drinking, personal and environmental hygiene such

*Author for Correspondence

as washing and bathing. Water can be obtained from many different sources including streams, lakes, ponds, rain and groundwater across coastal and inland environments. Water derived from most of these sources are usually visibly unclean, dirty and affected by various anthropogenic activities with the introduction of different chemical pollutants and microorganisms which renders it unwholesome and unfit for human consumption. Paun *et al.* (2016) stated that the most important sources of drinking water in all nations are surface water (streams, lakes, ponds) and groundwater (boreholes and wells).

Water consumers generally desire potable and quality water with respect to safety in order to maintain health and sustain life. Potable water is safe to drink, pleasant to taste, usable for domestic purposes and free from pathogens and chemical substances with potentials to impair health and jeopardize the wellbeing of consumers. Water quality is threatened by several pollutants consisting mainly of sewage, domestic waste, heavy metals, microorganisms, fertilizers and thousands of toxic metals and organic compounds (Bashir and Olalekan, 2012; Anake *et al.*, 2013). These pollutants alter the chemical, physical and biological characteristics of water which in turn describe its quality usually with respect to its suitability for a defined purpose (Stupar *et al.*, 2022) relative to set standards of its purpose or any human need. Tyagi *et al.* (2013) and Britto *et al.* (2018) reported that the quality of any specific water body can be tested and determined using the physical, chemical and biological parameters (variables) which include pH, turbidity, temperature, concentration of dissolved oxygen, nitrate, total suspended solids, electrical conductivity (EC), biological oxygen demand, heavy metals and bacteria levels.

Atiku *et al.* (2018) stated that natural groundwater is of good quality but deteriorates due to inadequate source of protection and poor resource management. Groundwater is frequently exposed to the risk of pollution due to permeability of overlying soil layers and numerous sources of pollution (Singh *et al.*, 2012). Contamination of groundwater can result from different human activities which include indiscriminate disposal of untreated waste, closeness of borehole to septic tanks, pit latrines and graves, poor agricultural practices as well as insanitary condition during borehole drilling and construction, runoff into wells especially if left uncovered and flooding at borehole site (Kelly *et al.* 2011; Essien and Bassey. 2012). However, the rate of groundwater contamination from these various sources can be influenced by several factors including the characteristics of leachates, hydrogeological conditions and the physicochemical properties of the soil (Al Muhsen *et al.*, 2019; Zeng *et al.*, 2021).

Contaminated water results in poor water quality. Poor water quality is largely attributed to low level of personal hygiene and inadequate treatment facilities for water and wastes that are consequent pollutants (Obilonu *et al.*, 2013) which can jeopardize and impair human and ecosystem health. Contaminants such as bacteria, fungi, protozoans, viruses, heavy metals, nitrates and salts have polluted water supplies due to inadequate treatment and poor disposal of wastes from humans and livestock, industrial discharges and over-use of limited water resources (Onyango *et al.*, 2018). Contamination of water by microorganisms and chemicals may impact odour, colour and taste on the water and as well renders it unfit for consumption with the consequence of social and economic damages thorough imposed water-related disease burden and death. The greatest risk to public health from microbes in water is associated with the consumption of drinking-water that is contaminated with human and animal excreta, although, there may be other significant sources and routes of exposure (WHO, 2022). Heavy metals including but not limited to cadmium, chromium, cobalt, mercury, and lead can be released into water from various natural or anthropogenic processes. These metals when present in low concentrations are essential for the development of

metabolic processes in plants and animals (Drasovean and Murariu, 2021). However, if these metals occur in elevated concentrations, they can exert profound effects on water quality and become toxic and threat to human lives (Drasovean and Murariu, 2021). The population mostly affected by waterborne diseases according to WHO (2022) are infants, young children, the elderly and people with compromised immune system especially when living under unhygienic conditions.

The inability of government to provide potable water for the ever-growing population has led to water stress and over dependence of people on alternative water sources such as streams, rivers, hand- dug well and borehole which are mostly chemically and microbiologically unmonitored, untreated, and unprotected groundwater or surface water. The sources and quality of drinking water in the coastal area of Ondo State, Nigeria call for general concern because of the potential sources of surface and groundwater contamination such as oil prospecting and mining activities, farming and life style of the people in the area which result in potential health risk of the people in the locality. Therefore, this study was designed to assess the microbial and physicochemical quality of groundwater in the coastal environment of Ondo State, Nigeria in order to ascertain the level of safety to consumers.

MATERIALS AND METHODS

Study Area

The study was conducted in Igbobini, Irele and Omin and Igbokoda in Ese-Odo, Irele and Ilaje Local Government Areas (LGAs) of Ondo State with Ijaw- Apoi, Ikale and Ilaje speaking ethnic nationalities respectively as inhabitants of these LGAs.

Collection of Water Samples

Triplicates of water samples were aseptically collected in 500 mL sterile screw-capped polypropylene bottles from seven boreholes and two wells (groundwater) following the ISO 5667-11:2009 standard and transported immediately to the laboratory in a cool box maintained at approximately 4 °C to avoid changes in parameters and were analyzed within 12 h after collection. Table 1 shows the nature, usage and location of underground water samples used in this study.

Table 1: Description of the nature, usage and location of underground water samples

S/N	Sample code	Nature of sample	Usage	Location	Latitude	Longitude
1	GB-S	BH	CM	Sunomo, Igbokoda	6° 23'11.136''	4° 46'12.966''
2	GB-M	HDW	GP	Akins Motel, Igbokoda	6° 21'21.546''	4° 48'3.942''
3	GB-P	HDW	GP	Olugbokoda Palace, Igbokoda	6° 21'15.384''	4° 47'47.154''
4	IR-O	BH	CM	Seja Omin	6° 28'45.156''	4° 53'17.7042''
5	IR-E	BH	CM	Ebute Road, Ode-Irele	6° 29'30.492''	4° 51'50.743''
6	IR-GH	BH	PU	General Hospital, Ode-Irele	6° 29'36.984''	4° 51'43.638''
7	IG-MR	BH	GP	Market Road, Igbobini	6° 30'4.59''	4° 49'20.976''
8	IG-HC	BH	PU	Health Centre, Igbobini	6° 30'5.01''	4° 49'17.802''
9	IG-BM	BH	CM	Bestman, Igbobini	6° 30'27.12''	4° 49'16.98''

Key: BH; Borehole, HDW; Hand-dug well, CM; Commercial, PU; Public Utility, GH; General Hospital, GP; General Purpose, MR; Market Road; HC; Health Centre, BM; Bestman,

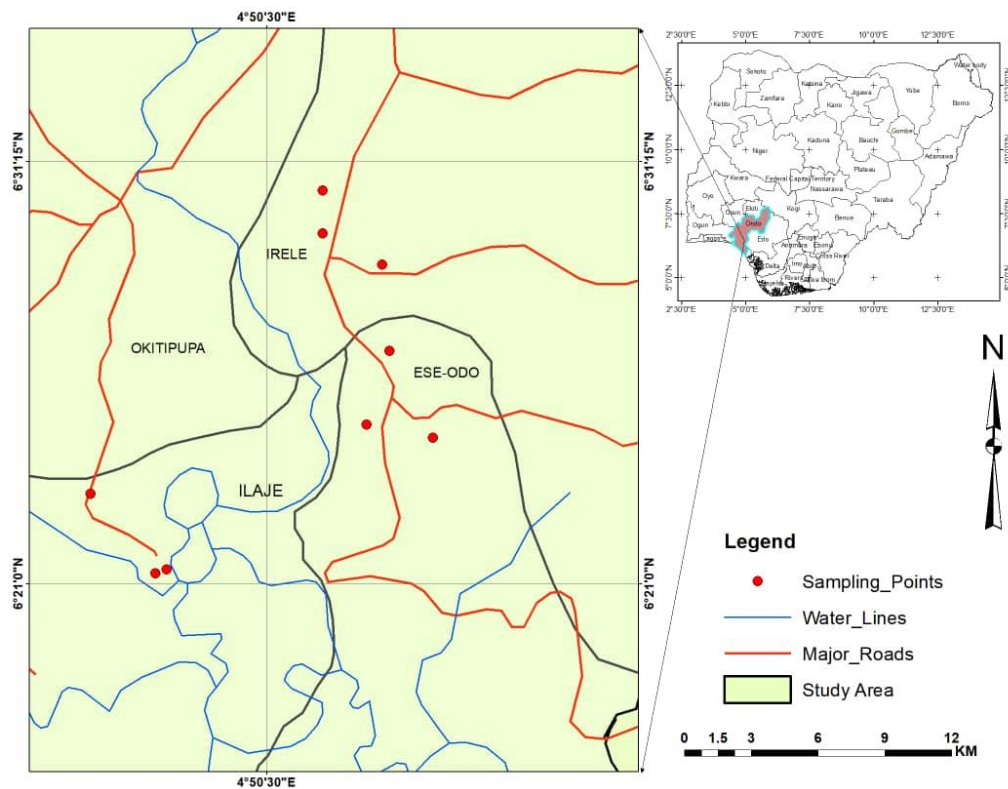


Figure 1: Map showing the sampling locations in the coastal region of Ondo State, Nigeria

Examination of Microbiological Quality of Water Samples

Enumeration of microorganisms from samples

Microbial contamination of the water samples was analyzed by the determination of total bacterial, total coliform and fungal counts. Based on standard techniques for microbiological analysis, viable and cultivable microorganisms were targeted. The pour plate method was used for the enumeration of bacteria and fungi by employing serial dilution. Tenfold serial dilutions of the groundwater samples were carried out aseptically. Exactly 0.1 mL aliquot from each of the dilution was inoculated into different sterile Petri dishes and separately overlaid with sterilized molten nutrient agar (NA) and potato dextrose agar (PDA) and then incubated at 37 °C for 24 hours and 28 ± 2 °C for 72 hours for bacterial and fungal quantification respectively. Colony counting was carried out by counting the number of visible colonies that appeared on the plates and expressed as colony forming unit or spore forming unit per 100 milliliters (CFU/100 mL or SFU/100 mL) of water sample for bacteria and fungi respectively.

Enumeration of total coliform

The three- tube assay (3-3-3 regime) of the standard multiple tube fermentation also referred to as Most Probable Number (MPN) index technique was used to detect and quantify coliform in the selected water samples. This involved the three stages; namely presumptive test, confirmative test and complete test. From the combined numbers of positive tubes in each set, the MPN of coliform bacteria present in the original water sample was appropriately determined using a standard MPN table developed by McCrady to obtain the estimated number of coliform cells present in 100 mL of original sample. The confirmed test was done

on the MPN positive tubes which were sub - cultured on Eosin Methylene Blue (EMB) agar and incubated 37 °C for 24 hours and then observed for greenish metallic sheen typical colonies of *Escherichia coli*. No completed test was carried as there were no plate with positive confirmatory test result.

Determination of physicochemical quality of water samples

The water samples collected were analyzed for colour, temperature, pH, electrical conductivity, total dissolved solid, total suspended solid, total solid, turbidity, salinity, dissolved oxygen, biological oxygen demand, alkalinity, acidity, nitrate, phosphate, sulphate and chloride by conventional physical and chemical analytical techniques described by APHA (2005).

Statistical Analysis

Data were analyzed statistically by using analysis of variance (ANOVA) and significant means were separated using new Duncan's Multiple Range test while the significance level was 5% level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Microbial Loads in the Assayed Underground Water Samples

This study revealed significant and varying degree of bacterial and fungal contamination of the groundwater samples. The microbiological quality of the water samples is shown in Figures 2, 3 and 4. Figures 2 and 3 revealed the total bacterial and total coliform counts detected in the samples in the range of 60.00 to 85.00 (CFU/100 mL) and 6.00 to 24.00 (MPN/100 mL) respectively while Figure 4 shows the fungal counts of the water samples in the range of 10.67 to 34.67 (SFU/ 100 ml). These values were higher than the set limit prescribed for drinking water by the WHO. Results revealed that for all the microbial types IR - O sample from Irele LGA had the highest counts of viable bacteria, coliform and fungal counts of 85.00 (CFU/ 100 mL), 24.00 (MPN/100 mL) and 34.67 (SFU/ 100 mL).

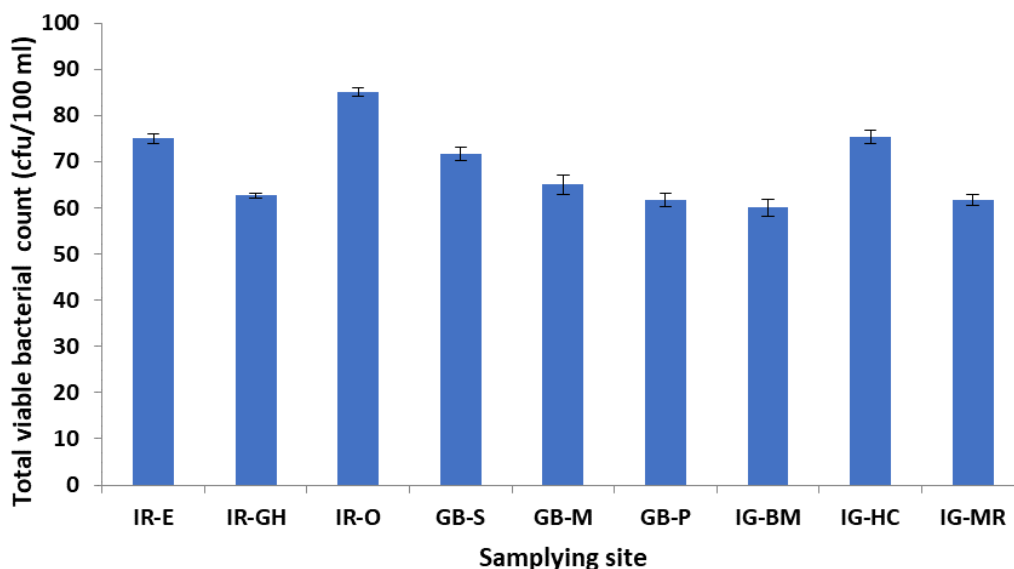


Figure 1: Total viable bacterial counts in selected underground water samples

Keys: IR-E; Ebute Road, Irele, IR-GH; General Hospital Irele, IR-O; Omi, GB-S; Sunomo, Igbokoda, GB-M; Akins Motel Igbokoda, GB-P; Olugbokoda Palace; IG-BM, Bestman Avenue, Igbibini, IG-HC, Igbobini Health Centre IG-MR; Market Road, Igbobini.

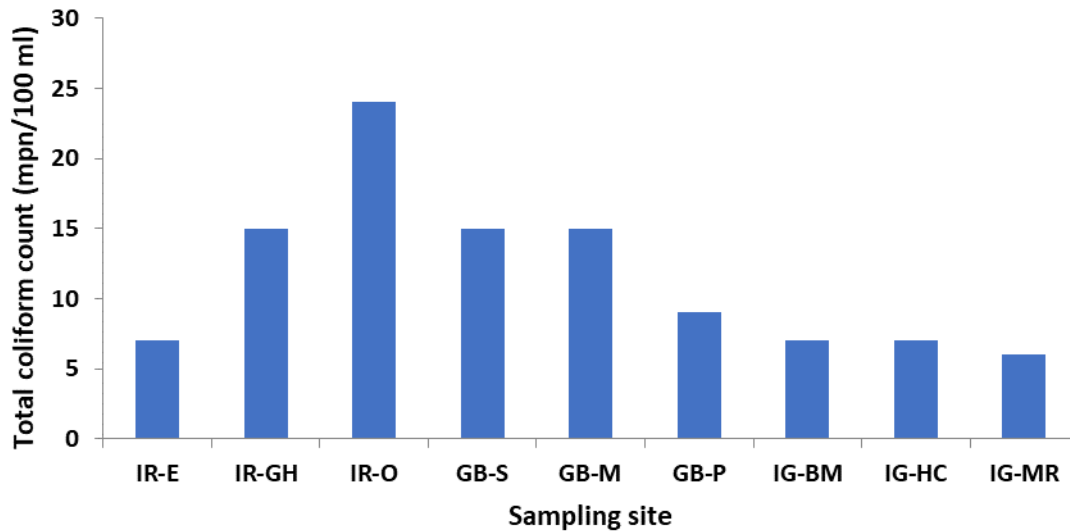


Figure 2: Total coliform counts in the selected underground water samples

Keys: IR-E; Ebute Road, Irele, IR-GH; General Hospital Irele, IR-O; Omi, GB-S; Sunomo, Igbokoda, GB-M; Akins Motel Igbokoda, GB-P; Olugbokoda Palace; IG-BM, Bestman Avenue, Igbibini, IG-HC, Igbobini Health Centre IG-MR; Market Road, Igbobini

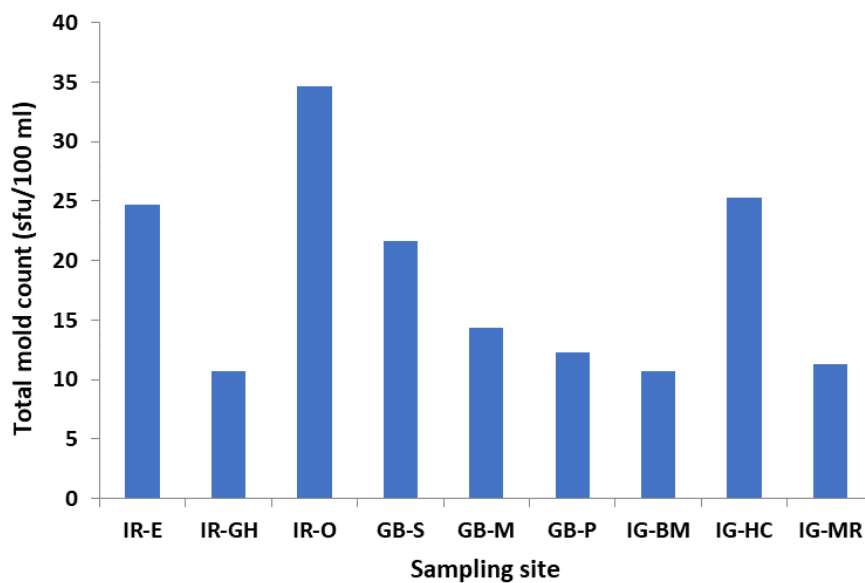


Figure 3: Total fungal counts in the selected underground water samples

Keys: IR-E; Ebute Road, Irele, IR-GH; General Hospital Irele, IR-O; Omi, GB-S; Sunomo, Igbokoda, GB-M; Akins Motel Igbokoda, GB-P; Olugbokoda Palace; IG-BM, Bestman Avenue, Igbibini, IG-HC, Igbobini Health Centre IG-MR; Market Road, Igbobini.

Water is a vital and unique chemical resource needed by all life forms for the sustenance of life and health. The consumption of contaminated or poor - quality water can elicit diseases and death among different age groups. The most vulnerable groups are the children, elderly and those with compromised immune system (Atiku *et al.*, 2018). Adequate supply of safe - drinking water will improve human health and reduce the burden of waterborne diseases. The World Health Organization and other agencies such as National Environment Commission (NEC) and Secondary Drinking Water Regulations (SDWR) are concerned about

public health and have set standard limits for water safety in order to overcome disease burden and death due to poor water quality.

The maximum contaminant level (MCL) for bacteria in drinking water is zero total coliform colonies per 100 milliliters. The total coliform test which is an easy and inexpensive to perform test is the required basic parameter for determining the biological quality of water. The assayed water samples differed in their water quality indicators with all the samples harboring coliform bacteria and fungal counts higher than the set limit of zero (0/100 mL) and 10 SFU/ 100 mL prescribed WHO limit. However, all the samples contained total coliform of less than 50 MPN/100 mL limit of NEC (2018). These results corroborate the assertion of Okomoda *et al.* (2014) that water houses the largest number of living organisms compared with other habitats and ecosystems. The presence of coliform bacteria in these water samples establishes that a possibility for disease - producing (pathogenic) organisms exist. However, there may or may not be pathogenic organisms in the water samples, but suggests that steps such as chlorination must be taken to eliminate the potential pathogens. Anon (2009) reported that runoff from feedlots, pastures, dog runs, and other land areas containing other animal wastes are potential sources of bacterial contamination of groundwater. The report stated further that wells that are open at the land surface, lack water-tight casings or caps that are shallow, or do not have a grout seal in the annular space are more vulnerable to contamination from these sources. The absence of *Escherichia coli* in the samples also suggested that the samples were free from faecal contamination.

Physicochemical Properties of the Assayed Underground Water Samples

Apart from biological indicators of water quality, the physicochemical variables are also critical in order to determine the quality of water for any intended usage. The physicochemical parameters of the selected underground water samples are shown in Table 2. There was no significant difference at $p < 0.05$ in the temperature of all the water samples and they were within the standard range of 25.01 and 25.8 and are therefore within the WHO permissible limit of 25 -28.

pH is one of the most critical indicators for determining water quality. It is a parameter that measures how acidic or alkaline a medium is on a scale of 0 - 14. pH value of 7 expresses neutral while less than 7 and above 7 indicate acidic and alkaline conditions respectively (Ikuesan and Balogun, 2022). The pH (4.2-5.16 and 4.25 - 5.21) of the water samples from Irele LGA (IR-E, IR-GH and IR-O) and Ese-Odo LGA (IG- BM, IG-HC and IG- MR) respectively were not also significantly different ($p < 0.05$) from each other. Similarly, sample GB-S from Ilaje LGA had an acidic pH of 5.23 which is also below the WHO limit while samples GB-M and GB-P pH values were 7.23 and 6.58 respectively. All the water samples except GB-M (pH 7. 23) were acidic with pH value ranging from 4.20 to 6.58. The acidic pH values (4.2-5.23) recorded for most of the samples are below the permissible limits of 6.5-8.5 for safe- drinking water recommended by WHO, NEC and NSDWR. The low pH values obtained in Ese - Odo (Igbobini), Irele LGA and GB - S study sites can be ascribed to run off and seepage due intense level of agricultural activities involving the use of fertilizers since the people and residents engage predominantly in oil palm production, cassava, maize, fruits and vegetables farming. The acidic nature of the assayed groundwater can also be due to oil pollution seepage into the aquifer. This assertion is derived from Ikuesan *et al.* (2019) who stated that the pH of oil polluted soil progressively decreased. However, Ejeomo *et al.* (2022) attributed the low pH obtained in a previous similar study to acid rain in the locality which Amaize and Onuegbu, (2018) reported to be due to crude oil and natural gas exploration and production operations. Therefore, acid rain and its effect on the pH of groundwater in the coastal region under study is expected because of crude oil exploration and gas flaring activities along the coastline. Nsi

et al. (2020) obtained acidic pH (5.9 – 6.8) in a similar study in Akwa Ibom State and reported that acidic pH levels can corrode plumbing and leach metal and concluded that children are at greater risk because their rapidly growing body absorb contaminants than adults.

The EC values ranged 18.1 – 372 $\mu\text{S}/\text{cm}$, 35.9 – 1789 $\mu\text{S}/\text{cm}$ and 59.3 – 254.00 $\mu\text{S}/\text{cm}$ respectively for Irele, Ese – Odo and Ilaje LGAs. The values of EC among the samples were significantly different from each other. The values of EC for Irele and Ese – Odo LGAs are below the set limit of both WHO and NEC. The samples GB-M and GB-P from Ilaje LGA having values of $1784.02 \pm 3.29 \mu\text{S}/\text{cm}$ and $997.1 \pm 1.30 \mu\text{S}/\text{cm}$ respectively were above 800 $\mu\text{S}/\text{cm}$ set limit by NEC. The values of total dissolved solid in sample IR-E (262.90 mg/L), GB-M (1260.0 mg/L), GB-P (707.0 mg/L) are higher than others. Although, only the values for GB – M and GB – P were above the 600 mg/L limit of WHO. Results revealed that the dissolved oxygen and biochemical oxygen demand of all the water samples ranged from 3.05 -3.9 (mg/L) and 0.05 – 1.0 (mg/L) respectively. These values did not exceed the standard limit of 6.0 and 2.0 mg/L respectively of NEC. With the exception of EC and TDS in which GB-M and GB-P which were hand-dug wells showed values above the allowable limit, all the mean physicochemical parameters recorded for the water samples from the various sampling points across the three LGAs were far below the permissible limits indicated by regulatory agencies. It is presumed that high TDS in GB-M and GB-P could be suggestive of the high dissolved mineral content of the water samples. Alkalinity relates to the ability of water to neutralize acids. With the exception of samples GB-M and GB-P which recorded alkalinity values of 516 mg/L and 184 mg/L, the alkalinity for all the other samples were below limits of less than 150 mg/L.

Concentrations of Heavy Metals in the Assayed Underground Water Samples

The samples had varying concentrations of heavy metals as shown in Table 3. Among the metals, Cu, Fe, Mn and Zn had the highest concentrations which ranged from 0.171 – 0.316 mg/L, 0.115 – 0.348 mg/L, 0.183 – 0.311 mg/L and 0.132 – 0.376 mg/L respectively. IR – E and IR – GH had Fe concentrations higher than the 0.3 mg/L allowable limit of WHO. Similarly, the concentration of chromium 0.067 mg/L in sample GB – M was also higher than the 0.05 mg/L allowable limit set by WHO and NEC. Except for sample GB – M which had 0.001 mg/L of Ni, all the samples showed undetectable amount of Cd and Ni.

Assessment of the Microbial and Physicochemical Quality of Water: Evidence from Selected Groundwater Sources from The Coastal Region of Ondo State, Nigeria.

Table 2: Physicochemical Characteristics of the Assayed Underground Water Samples

Parameters	WHO	NEC -2018	IR-E	IR-GH	IR-O	GB-S	GB-M	GB-P	IG-BM	IG-HC	IG-MR
True Colour (TCU)	< 15	5	5±0.01	2.99±0.00	5±0.00	7±0.00	10±0.01	4±0.00	4±0.01	4.01± 0.01	4±0.00
Temperature (°C)			25.1±0.00	25.01±0.00	25.5±0.00	25.4±0.01	25.1±0.00	25±0.00	25±0.00	25.8± 0.01	25.6±0.00
pH (at 25 °C)	6.5-8.5	6.5-8.5	4.2±0.01	4.74±0.00	5.16±0.01	5.23±0.00	7.23±0.00	6.58±0.00	4.25±0.00	5.21± 0.00	4.63±0.01
Electrical Conductivity (µS/cm)	400		372±0.00 ^s	116.2±0.00 ^h	18.1±0.00 ⁱ	35.9±0.00 ^c	1784±0.00 ^a	997.1±0.00 ^b	59.3±0.00 ^d	254± 0.00 ^e	72.3± 0.00 ^f
Total Dissolved Solids (mg/L)	< 600		262.9±0.00 ^s	82.3±0.00 ^h	12.8±0.00 ⁱ	25.4±0.00 ^c	1260±0.00 ^a	707±0.00 ^b	41.9±0.00 ^d	179± 0.01 ^e	51.2±0.00 ^f
Total Suspended Solids (mg/L)		25	1.0±0.01 ^s	116.4±0.00 ^h	1.9±0.00 ⁱ	0.9±0.00 ^c	108.0±0.00 ^a	7.0±0.00 ^b	1.1±0.01 ^d	1.8± 0.00 ^e	2.0±0.01 ^f
Total Solids (mg/L)			263±0.00 ^s	198.7±0.00 ^h	14.7±0.00 ⁱ	26.3±0.00 ^c	1368±0.00 ^a	714±0.00 ^b	43± 0.01 ^d	180.8±0.01 ^e	53.2±0.00 ^f
Turbidity (NTU)	< 4		0.52±0.00 ^s	0.31±0.00 ^h	1.37±0.01 ⁱ	0.73±0.00 ^c	3.41±0.00 ^a	4.06±0.00 ^b	0.15±0.01 ^d	1.16±0.00 ^e	1.33±0.01 ^f
Salinity (ppt)			0.18±0.00 ^f	0.05±0.00 ^s	0.01±0.00 ⁱ	0.02±0.00 ^c	0.89±0.00 ^a	0.49±0.00 ^b	0.03±0.00 ^d	0.12±0.00 ^e	0.03±0.00 ^{af}
Dissolved Oxygen (mg/L)		6	3.05±0.00 ^s	3.11±0.01 ^a	3.3±0.00 ^b	3.9±0.01 ^c	3.11±0.00 ^a	3.3±0.00 ^b	3.45±0.00 ^d	3.2±0.00 ^e	3.23±0.00 ^f
BOD (mg/L)		2	0.15±0.00 ^f	0.19±0.01 ^s	0.06±0.01 ^{af}	0.05±0.00 ^c	1 ±0.00 ^a	0.31±0.00 ^b	0.11±0.00 ^d	0.07±0.00 ^e	0.1±0.01 ^f
Alkalinity (CaCO ₃ , mg/L)			-	-	0.08±0.01 ^d	0.12±0.00 ^c	516±0.01 ^a	184±0.00 ^b	-	0.11±0.01 ^e	-
Acidity (CaCO ₃ , mg/L)			54±0.01 ^f	23.5±0.01 ^s	19±0.01 ^h	26.9±0.00 ^c	91.91±0.00 ^a	36±0.01 ^b	15±0.01 ^d	16.5±0.00 ^e	36±0.01 ^h
Nitrate (mg/L, NO ₃ -)	50	10	46.31±0.00 ^s	17.42±0.00 ^h	2.03±0.00 ⁱ	4.99±0.01 ^c	3.75±0.00 ^a	41.16±0.00 ^b	11.89±0.00 ^d	10.64±0.00 ^e	15.23±0.00 ^f
Phosphate (mg/L, PO ₄ -)	2	0.5	1.11±0.00 ^s	2.05±0.00 ^h	2.03±0.00 ⁱ	4.99±0.00 ^c	2.19±0.00 ^a	1.43±0.01 ^b	0.87±0.01 ^d	1.93±0.01 ^e	1.72±0.01 ^f
Sulphate (mg/L, SO ₄ -)	250	25	5.1±0.00 ^f	6±0.00 ^s	5.9±0.00 ^h	5.2±0.00 ^c	11.2±0.01 ^a	80±0.00 ^b	5.2±0.00 ^d	5±0.00 ^e	7.8±0.00 ^f
Chloride (mg/L, Cl-)	250	50	32.42±0.01 ^s	10.08±0.01 ^h	3.6±0.01 ⁱ	5.77±0.01 ^c	216.02±0.01 ^a	79.21±0.00 ^b	7.55±0.00 ^d	7.92±0.00 ^e	7.2±0.00 ^f

Values along rows with dissimilar alphabet are significantly different at $p < 0.05$
 Values are presented as mean ± standard error, values in the same row carrying same superscript are not significantly different using new Duncan Multiple range test at $p \leq 0.05$
 Legend: IR-E, IR-GH and IR-O Irele LGA; GB-S, GB-M and GB-P from Ilaje LGA B; IG-BM, IG-HC and IG- MR from Ese-Odo LGA, + = present, - = absent, EPA - environmental protection agency, TCU - True Color Unit, NTU - Nephelometric Turbidity Unit, Nil = < 0.1 mg/L or not detected, WHO; World Health Organization, NEC; National Environment Commission

Table 3: Concentrations of Heavy Metals in the Assayed Underground Water Samples

Metals mg/L	WHO (2022)	NEC	IR -E	IR -GH	IR - O	GB -S	GB -M	GB -P	IG -BM	IG -HC	IG -MR
As	0.01	0.01	0.005± 0.000 ^b	0.001± 0.000 ^a	0.003± 0.001 ^a	0.001± 0.000 ^a	0.003± 0.001 ^a	0.001± 0.000 ^a	0.003± 0.001 ^a	0.002± 0.000 ^a	0.002± 0.000 ^a
Cd	0.003	0.003	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	0.05	0.05	0.027± 0.002 ^{ef}	0.03± 0.001 ^{de}	0.022± 0.001 ^{bf}	0.01± 0.000 ^c	0.067± 0.002 ^a	0.019± 0.003 ^{bf}	0.016± 0.002 ^{bc}	0.019± 0.001 ^b	0.036± 0.001 ^d
Co			0.008± 0.001 ^c	0.006± 0.001 ^{ac}	0.011± 0.001 ^d	0.001± 0.000 ^b	0.004± 0.001 ^{ab}	0.001± 0.000 ^b	0.001± 0.000 ^b	0.002± 0.001 ^b	ND
Cu	2.0	0.05	0.306± 0.001 ^g	0.316± 0.001 ^g	0.292± 0.001 ^a	0.193± 0.004 ^c	0.287± 0.004 ^a	0.171± 0.004 ^b	0.264± 0.002 ^d	0.246± 0.006 ^e	0.219± 0.001 ^f
Fe	0.3	0.2	0.308± 0.004 ^g	0.348± 0.004 ^h	0.295± 0.003 ⁱ	0.135± 0.003 ^c	0.184± 0.003 ^a	0.115± 0.001 ^b	0.211± 0.002 ^d	0.234± 0.001 ^e	0.249± 0.001 ^f
Mn	0.08		0.278± 0.001 ^f	0.258± 0.002 ^g	0.311± 0.001 ^h	0.194± 0.003 ^c	0.205± 0.004 ^a	0.183± 0.002 ^b	0.232± 0.003 ^d	0.201± 0.003 ^{ac}	0.217± 0.002 ^e
Ni	0.07		ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	0.01	0.02	0.033± 0.001 ^e	0.038± 0.001 ^e	0.024± 0.002 ^b	0.01± 0.001 ^d	0.021± 0.001 ^{ab}	0.014± 0.002 ^{ad}	0.017± 0.002 ^{ac}	0.014± 0.001 ^{cd}	0.01± 0.000 ^d
Zn	3	0.2	0.317± 0.004 ^f	0.294± 0.001 ^g	0.376± 0.002 ^h	0.132± 0.002 ^c	0.233± 0.001 ^a	0.185± 0.001 ^b	0.211± 0.001 ^d	0.197± 0.002 ^e	0.227± 0.001 ^a

Values are presented as mean ± standard error and values along rows with dissimilar alphabet are significantly different at $p < 0.05$

Key: TCU - True Color Unit, NTU - Nephelometric Turbidity Unit, ND - Not Detected

The concentrations of the heavy metals varied in all the samples with Cu, Fe and Mn exceeding the 2.0, 0.2, 0.08 and 3 mg/L respectively in some samples. The sources and toxicological effects of these metals in water differ. According to the WHO (2022) Cu is both an essential nutrient and drinking water contaminant with gastrointestinal effect in elevated concentration while chromium can cause hyperplasia in the small intestine. Manganese is an essential trace element but can induce neurological effects (including reduced cognitive ability) in adults and children after ingestion of manganese - contaminated water.

CONCLUSION

The assessment of the water samples for biological indicators (coliform and heterotrophic bacterial) suggested that all the water samples contain coliform bacteria in a number exceeding the WHO standard and therefore were microbiologically unfit for drinking, cooking, brushing teeth, etc. but rather suggested the need to identify the pathway and eliminate the source of contamination. The assessed water quality indices of groundwater samples revealed that water from these sources need to be treated prior to domestic usage particularly drinking. Therefore, there is a need for water quality monitoring and intervention by government and oil multinationals operating in the area by providing potable water for the people of the coastal environment noting that adequate supply of safe - drinking water will reduce the burden of waterborne diseases and improve human health.

COMPETING INTERESTS

The authors declared that they have no competing interests in this research.

AUTHORS' CONTRIBUTIONS

Authors FAI and TFE both conceived and designed the project. Author FAI performed the microbiological and part of the physicochemical analyses. TFE carried out the research on the major part of the physicochemical studies. Both authors participated in literature search while the manuscript was developed and prepared by FAI. FAI and TFE both contributed to data analysis and the correction of the final manuscript.

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