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Pollution and Human Health Risks Assessment of drinking water in Ondo Southern Riverine Communities of Nigeria

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Abstract

Despite the free access to and consumption of quality drinking water, which is essential for human well-being, both natural occurrences and anthropogenic activities worldwide have significantly compromised the quality of drinking water, thereby reducing its availability and safety. This study examined the pollution levels in drinking water and the associated health risks in selected communities of Ondo State, Nigeria. One hundred water samples were obtained from drinking water sources in ten selected riverine communities in Ondo South. The evaluation of physicochemical parameters, toxic metals, and microbial load was conducted in accordance with APHA, USEPA IRIS, and WHO guidelines. The results indicated that concentrations of toxic metals and physicochemical parameters exceeded the permissible limits set by WHO and USEPA IRIS. Gram staining and IMViC tests verified the presence of fecal coliforms, indicating fecal contamination against the WHO standards. Chronic Daily Intake (CDI) ranks as follows: Babies > Children > Adults, whereas the cancer risk hierarchy is As > Cd > Cr. The Hazard Quotient is in the order Pb > As > Cr > Cd, significantly surpassing the permissible limit of less than 1. The analysis concludes that drinking water in the study areas presents a risk for diseases such as diarrhea, cholera, and cancer. The elevated water pollution in these study areas results from the presence of chemicals, specifically heavy metals, and microbial contaminants originating from household waste.

INTRODUCTION

Water, a colorless, odorless liquid composed of hydrogen and oxygen, dissolves many different compounds. All forms of life, including the production of food and progress, depend on water [1]. Sustainable development in each human group is dependent on a steady supply of water. SDG 6 calls for all countries to ensure their citizens have ready access to clean water by 2030 [1]. Unfortunately, over a billion people across the globe cannot access potable water [2]. Previous studies have revealed that close to a million people in developing countries die yearly due to consumption of polluted water, with a higher percentage recorded among children. These estimated values are expected to rise in the coming years due to increasing natural disasters and continuous anthropogenic activities of humans [2,3]. Urbanization and industrialization are reported as being the major contributors to water contamination [4,5]. Due to industrial operations that have brought pollutants into the environment over the years, pollution of the drinking water sources is now creating a severe concern across the nation in a developing country like Nigeria. Human health and ecosystems are negatively impacted by the untreated discharge of about 80% of global industrial and municipal wastewater. This percentage is higher in developing countries because of inadequate sanitation and wastewater treatment [5]. The populace is susceptible to water-related diseases, including cholera, typhoid, hepatitis A, diarrhea, and dysentery, as a result of inadequate sanitation systems and water pollution [6].

Heavy metal contamination can adversely impact the physical, chemical, and biological properties of water, posing a significant concern to consumers. Heavy metals typically enter the environment as a result of industrial processes, agricultural practices, and various human activities that negatively impact the

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ecosystem [7,8]. Heavy metals promote a variety of enzymatic and metabolic processes in living things when they are present in drinking water below safe limits. However, when their concentrations are beyond the maximum contamination levels, they become hazardous. According to reports, toxic metals like lead and mercury can cause significant harm to the body by building complexes with metabolic enzymes and interfering with their physiological pathways [9-11].

Since the discovery of oil in the 1960s, Nigeria has relied heavily on the proceeds from the export of crude oil and processed products to earn foreign currency. Despite its huge impact on the national economy, oil spills occur often during the extraction and transportation process, causing water pollution and consequently affecting edible water bodies and agricultural activities of residents. In time after oil discovery in the Ilaje area of Ondo state, water pollution due to oil leaks has been a major setback to access good quality water in these areas and has affected thousands of people [12]. This study aims to evaluate the effects of oil contamination on the water quality of the region by assessing physicochemical parameters, bacterial load, and heavy metal concentrations in drinking water, as well as the direct health implications of consuming oil-contaminated water, including long-term and chronic health issues, while also deepening the understanding of the wider consequences of environmental pollution.

MATERIALS AND METHODS

A total of 100 drinking water samples were randomly collected from drinking water sources across ten (10) coastal communities of Ilaje LGA into ice-chested sterile containers and immediately transferred to the Microbiology laboratory of Olusegun Agagu University of Science and Technology for microbiological and biochemical analyses.

Study Area

The Ilaje communities, where samples were collected for analyses, are a coastal region that is located in the Ilaje local government area of Ondo state, Nigeria. Ilaje LGA has over three hundred communities in her riverine areas, with some of them directly on the waterways across the LGA. The LGA lies between Latitude 5°54' and 6°29' North and Longitude 4°27' and $5^0$02' East respectively. Water sample collection was from Ugbonla to Obenla. The map of Ondo state (**Fig. 1**), revealing Ilaje Local Government Area (LGA) is as shaded in (a) while the satellite imaging of communities where samples were collected is shown in (b).

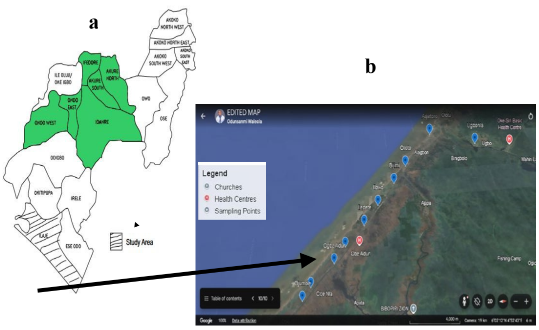

Fig. 1. (a) is the map of Ondo State, revealing the three senatorial districts and the study area (Ilaje LGA, shaded), while **(b)** reveals the satellite imaging of communities where water samples were taken in Ilaje LGA of Ondo State, Nigeria.

Bacteriological Analysis

The coliform count was determined using the tube assay of the Most Probable Number (MPN) technique as described by [13]. Gram staining and IMViC tests were used to confirm the presence of *E. coli* (faecal coliforms) in the water samples.

Physicochemical Analysis

The analysis of the water samples included measurements of Temperature, pH, Electrical Conductivity, Total Hardness (mg/L), Total Alkalinity (mg/L), Chloride (mg/L), total dissolved solids (ppm), Turbidity (NTU), and Dissolved Oxygen (mg/L). Measurements of temperature, pH, and electrical conductivity were conducted at the collection points. All physicochemical analyses were conducted in triplicate following established standard methods [13].

Elemental Analysis Uisng AGILENT 720 ICP - OES

Concentrated HNO_3(aq) was employed to digest the water samples in a microwave apparatus following the method outlined in [13]. The sample digest was diluted, supplemented with internal standards, and evaluated via inductively coupled plasma optical emission spectrometry (ICP-OES). Serial dilutions were employed to provide distinct concentrations for the working standards of each element. Calibration curves were subsequently established under standard conditions for the constituents of interest, utilizing appropriate wavelengths for their measurement. The metal concentrations in liquid samples were directly acquired from the equipment using the designated preset units.

Quality Control

The pH meter was standardized using solutions of buffer with pH values of 4.0, 7.0 and 12.0, while the cathodes and anodes of the EC meter were standardized using 0.01M KCl (1413 µS cm^{-1}). Blank samples as well as the triplicates of each sample were used to ensure the accuracy of analytical results. For heavy metals, spiked samples together with blanks were used with recovery rates sustained at 95 – 103% while detection limits for Cd, As, Pb and Cr were 1, 1, 3,1. Grade quality reagents were also used. All glassware used in the study were prepared by dipping it in 14% nitric acid overnight and then cleaned with deionized water.

Assessment of Human Health Risk

The underlisted formulae were used to calculate dose taken, risk of cancer, Risk sum and Hazard index (HI), respectively.
Dose taken (DT) or Chronic Daily Intake (CDI) was calculated using the equation below.

$$DT = DW * C/BW \qquad \text{(Eqn. 1) [14]}$$

Where:
DT = Dose taken in drinking water (mg $kg^{-1}day^{-1}$)
DW = Mean volume of water consumed everyday (L) {Adults, adults 2 L/day, Children 1 L/Day and infants 0.75L/Day [15]}
C = concentration of elements in water (mg L^{-1})
BW = Body weight (kg) {Adults,70Kg; Children 10Kg and Infants 5 Kg, [16]}

Incremental Lifetime Cancer Risk (ILCR)

$$ILCR = CSF \times CDI \qquad \text{(Eqn. 2) [14]}$$

where CSF is the Cancer Slope Factor and CDI is the Chronic Daily Intake

$$\text{Hazard Quotient (HQ)} = \frac{CDI}{R_{fD}} \qquad \text{(Eqn. 3) [17]}$$

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Where:

CDI = Chronic Daily Intake
R_{fD} = Reference dose of heavy metal [14]

The non-carcinogenic health risks are the non - cancerous side effects of ingestion of heavy metals in drinking water. The evaluation was conducted using the Hazard Quotient (HQ), defined as the ratio of the average daily dose (DT) to the reference dosage (RfD) of a certain metal. The hazard index (HI) is the sum of the hazard quotients for each metal.

Hazard index (HI) was calculated using.

$$HI = DT/RfD_1 + DT/RfD_2 + DT/RfD_n: [14] \quad 4$$

where:
DT Dose taken (mg/kg/day) and RfD is the reference dose (mg/kg/day)

Statistical analysis
The raw data collected for each parameter were statistically evaluated using IBM SPSS version 23. Descriptive statistics encompassed frequency distribution, mean, standard deviation, and range of several parameters. While inferential statistics were used to assess the spatial differences across the communities, one-way ANOVA and Kruskal-Wallis tests followed by Tukey's HSD post-hoc for ANOVA and Bonferroni-corrected Mann-Whitney U for Kruskal-Wallis.

RESULTS

Table 1 summarizes the physicochemical parameters of water samples collected from ten communities in the Ondo South Senatorial District. Analysis of most of the parameter values against WHO guidelines indicates that all communities exceeded acceptable limits. Specifically, temperature levels were all greater than 30°C, electrical conductivity exceeded 500 µS/cm in Communities 1, 2, and 4 to 9, total dissolved solids were above 500 ppm, turbidity levels surpassed 5 NTU, and total hardness exceeded the aesthetic threshold of 200 mg/L in Communities 1 and 9. Spatial variation exhibited randomness without a systematic upstream-downstream pattern; however, significant hotspots were identified, such as the lowest pH of 4.2 in Communities 2 and 5, and the highest electrical conductivity of 1670 µS/cm in Community 7. Spatial differences were assessed through one-way ANOVA and Kruskal-Wallis tests across 10 communities (n=3 replicates each; df_between=9, df_within=20), with Tukey's HSD and Bonferroni-corrected Mann-Whitney U post-hoc tests applied to significant outcomes. All parameters exhibited significant variation ($p<0.01$), despite random distribution.

Temperature (ANOVA $F(9,20)=66.41$, $p<0.0001$; $H=25.45$, $p=0.0025$; Tukey's 23 pairs significant, e.g., C3 vs C7 $p<0.001$; KW 0 pairs due to conservative correction), pH ($F=49.61$, $p<0.0001$; $H=26.21$, $p=0.0019$; 28 pairs), EC ($F=51.84$, $p<0.0001$; $H=27.40$, $p=0.0012$; 32 pairs), total hardness ($F=65.59$, $p<0.0001$; $H=27.77$, $p=0.0010$; 32 pairs, e.g., C1 vs C6 $p<0.001$), total alkalinity ($F=72.84$, $p<0.0001$; $H=25.23$, $p=0.0027$; 33 pairs), chloride ($F=89.41$, $p<0.0001$; $H=28.02$, $p=0.0009$; 37 pairs), TDS ($F=70.65$, $p<0.0001$; $H=27.86$, $p=0.0010$; 32 pairs), turbidity ($F=37.38$, $p<0.0001$; $H=25.76$, $p=0.0022$; 27 pairs), and dissolved oxygen (DO; $F=69.35$, $p<0.0001$; $H=27.71$, $p=0.0011$; 31 pairs).

Table 1. Physicochemical parameters of water samples collected from the communities. Data are mean ± SD.

	(WHO standards) [3,22]								
	25-39	6.50-8.50	≤250	20-120	80-200	≤250	300-500	≤ 5	≥ 6.5-8.0
Site	Temperature (°C)	pH	Electrical conductivity (µS/cm)	Total hardness (mg/L)	Total alkalinity (mg/L)	Chloride (mg/L)	Total Dissolved Solids (ppm)	Turbidity (NTU)	Dissolved oxygen (mg/L)
1	43.7 ± 0.1	5.8 ± 0.9	1022.3 ± 198.4	210.4 ± 20.3	78.5 ± 8.8	105.2 ± 5.7	753.9 ± 2.8	85.7 ± 9.5	5.7 ± 9.7
2	43.1 ± 0.3	4.2 ± 0.5	841.2 ± 395.1	128.8 ± 44.5	89.6 ± 3.6	113.4 ± 3.8	775.2 ± 6.0	165.4 ± 0.7	6.0 ± 9.7
3	35.5 ± 0.5	4.4 ± 0.4	400.3 ± 121.8	144.3 ± 47.9	86.7 ± 8.0	100.6 ± 0.3	810.1 ± 0.5	126.0 ± 8.8	6.2 ± 4.4
4	44.6 ± 0.8	5.5 ± 0.2	800.6 ± 48.2	149.1 ± 8.7	85.7 ± 0.8	125.1 ± 4.9	861.3 ± 1.8	115.2 ± 8.5	6.3 ± 0.1
5	43.0 ± 0.3	4.2 ± 0.1	230.5 ± 13.1	154.5 ± 7.7	100.0 ± 2.9	132.6 ± 9.3	863.9 ± 1.7	153.2 ± 4.3	6.5 ± 4.0
6	41.7 ± 0.4	6.4 ± 0.3	1242.7 ± 206.4	100.0 ± 0.1	98.3 ± 8.6	137.1 ± 4.6	890.1 ± 3.2	130.7 ± 8.6	5.9 ± 7.4
7	46.5 ± 0.2	6.1 ± 0.7	1670.0 ± 0.0	165.1 ± 10.4	97.8 ± 8.2	141.5 ± 9.3	958.9 ± 9.9	144.9 ± 5.2	6.5 ± 0.5
8	43.9 ± 0.6	7.5 ± 0.4	1584.1 ± 312.0	170.4 ± 1.5	91.3 ± 5.1	160.5 ± 5.9	980.6 ± 1.2	143.2 ± 7.9	5.2 ± 2.0
9	46.5 ± 0.3	6.2 ± 0.7	1612.9 ± 0.1	198.1 ± 2.5	98.1 ± 2.3	140.5 ± 3.6	990.5 ± 6.0	149.7 ± 9.5	6.7 ± 5.5
10	43.7 ± 0.5	5.8 ± 1.0	230.3 ± 5.3	103.3 ± 33.9	98.8 ± 9.4	157.8 ± 8.2	730.7 ± 4.4	142.1 ± 3.7	5.1 ± 7.1

Note: 1-10: Ugbonla, Oju Imole, Aiyetoro, Oroto, Bijimi, Ilowo, Ilepete, Ogbe Adun, Obe Adun, and Obe Nla respectively.
Data are expressed as mean ± SD. Samples (n=3) were obtained for each physicochemical parameter. The final results of these parameters are expressed as mean ± SD and compared with WHO reference standard

Table 2. Heavy Metals water samples collected in from the communities. Data are mean ± SD.

	(WHO standards) [3,22] (mg/L)										
	0.01	0.003	0.001	0.2	2.0	0.08	0.07	0.01	3.0	0.05	0.02
Site	Lead (Pb) (mg/L)	Cadmium (Cd) (mg/L)	Mercury (Hg) (mg/L)	Aluminum (Al) (mg/L)	Copper (Cu) (mg/L)	Manganese (Mn) (mg/L)	Molybdenum (Mo) (mg/L)	Arsenic (As) (mg/L)	Zinc (Zn) (mg/L)	Chromium (Cr) (mg/L)	Nickel (Ni) (mg/L)
1	181.00 ± 13.51	1.62 ± 0.15	0.04 ± 0.03	0.07 ± 0.01	68.67 ± 8.93	77.67 ± 9.75	0.090 ± 0.013	0.720 ± 0.107	13.48 ± 0.90	4.29 ± 1.12	0.18 ± 0.01
2	91.90 ± 12.56	1.49 ± 0.09	0.04 ± 0.02	0.02 ± 0.00	96.23 ± 26.90	77.06 ± 2.07	0.120 ± 0.001	0.710 ± 0.065	12.70 ± 1.11	3.09 ± 1.83	0.09 ± 0.02
3	156.57 ± 48.05	1.28 ± 0.53	0.02 ± 0.01	0.04 ± 0.01	96.82 ± 10.13	87.78 ± 3.01	0.090 ± 0.004	0.540 ± 0.038	12.57 ± 0.33	3.31 ± 1.55	0.09 ± 0.02
4	164.06 ± 23.49	1.83 ± 0.14	0.04 ± 0.03	0.03 ± 0.02	116.30 ± 10.42	51.80 ± 6.12	0.090 ± 0.003	0.780 ± 0.031	12.45 ± 1.12	1.42 ± 0.70	0.08 ± 0.02
5	163.16 ± 38.74	1.79 ± 0.03	0.05 ± 0.01	0.05 ± 0.02	74.12 ± 9.74	78.45 ± 8.23	0.100 ± 0.007	0.950 ± 0.015	12.65 ± 0.23	3.65 ± 1.15	0.10 ± 0.01
6	123.27 ± 32.13	1.27 ± 0.26	0.05 ± 0.03	0.07 ± 0.02	65.83 ± 12.81	81.57 ± 11.78	0.090 ± 0.003	0.730 ± 0.041	13.96 ± 1.21	4.45 ± 0.91	0.07 ± 0.00
7	154.19 ± 32.04	1.66 ± 0.21	0.04 ± 0.04	0.02 ± 0.01	5.67 ± 9.50	77.68 ± 7.18	0.090 ± 0.010	0.740 ± 0.025	13.76 ± 0.78	3.51 ± 1.79	0.12 ± 0.03
8	135.94 ± 26.64	1.76 ± 0.11	0.04 ± 0.02	0.08 ± 0.01	94.69 ± 9.56	68.70 ± 13.38	0.070 ± 0.001	0.780 ± 0.056	10.34 ± 0.20	3.57 ± 0.22	0.08 ± 0.02
9	143.74 ± 12.45	1.58 ± 0.03	0.02 ± 0.02	0.03 ± 0.01	117.95 ± 7.66	50.71 ± 1.57	0.090 ± 0.004	0.750 ± 0.038	19.57 ± 0.43	4.99 ± 0.53	0.08 ± 0.02
10	164.90 ± 13.65	0.62 ± 0.14	0.08 ± 0.02	0.05 ± 0.02	84.11 ± 26.36	70.46 ± 5.08	0.100 ± 0.004	0.690 ± 0.030	14.06 ± 1.16	5.35 ± 0.32	0.12 ± 0.05
Mean	145.71 ± 42.86	1.58 ± 0.27	0.008 ± 0.001	0.383 ± 0.287	82.03 ± 37.14	67.52 ± 17.09	0.095 ± 0.012	0.721 ± 0.148	13.51 ± 2.53	3.67 ± 1.27	0.099 ± 0.04

Note: 1-10: Ugbonla, Oju Imole, Aiyetoro, Oroto, Bijimi, Ilowo, Ilepete, Ogbe Adun, Obe Adun, and Obe Nla, respectively.
Data are expressed as mean ± SD. Samples (n=3) were obtained for each physicochemical parameter. Data are expressed as mean ± SD. Samples (n=3) were obtained for each physicochemical parameter. The final results of these metals are expressed as mean ± SD and compared with the WHO reference standard. ANOVA/Kruskal-Wallis with Tukey's HSD/Bonferroni post-hoc: Marginal for Pb ($F=2.41$, $p=0.0579$; $H=13.68$, $p=0.0906$; 0 pairs); no differences for others ($p>0.10$; 0 pairs). Uniform exceedances observed; low power note.

The small sample size (n=3/group) limited statistical power (~40–50% for medium effects); however, random hotspots indicate localized pollution sources. Heavy metal concentrations are summarized in **Table 2**, with all communities exceeding WHO limits for Pb, Cd, Hg, Al, Cu, Mn, Mo, As, Zn, Cr, and Ni (e.g., Pb means 117.4–169.7 mg/L >>0.01 mg/L). Random variation was observed, with hotspots like As in C2 (14.9 ± 8.3 mg/L) and Mn in C4 (81.4 ± 13.7 mg/L). Inferential statistics revealed non-significant variation across communities (p>0.10 for all; no post-hoc pairs significant), indicating uniform contamination despite random hotspots. **Table 3** presents the values obtained by applying equation 1 to assess the dosage taken (DT) or Chronic Daily Intake (CDI) by adults, children, and infants in the area.

Table 3. Heavy metals taken by grown - ups, children, and babies in the drinking water of the riverine communities based on data obtained from water samples.

Metals	Dose taken by adults (mg/kg/day)	Dose taken by Children (mg/kg/day)	Dose taken by Infants (mg/kg/day)
Pb	4.163	14.571	21.86
Cd	0.045	0.158	0.237
Mn	1.929	6.752	10.13
As	0.0206	0.0721	0.168
Zn	0.386	1.351	2.030
Cr	0.105	0.367	0.55
Ni	0.0028	0.0099	0.015
Al	0.0109	0.0388	0.057
Hg	0.0002	0.0008	0.0012

Table 4 revealed the Cancer Slope Factor (CSF) values for arsenic, chromium, lead, and cadmium. The carcinogenic slope factors for the metals are as follows: 32 (mg/kg-day)$^{-1}$ for arsenic [14], 0.3 (mg/kg/day)$^{-1}$ for chromium [15], this value applies to exposures beginning in adulthood, not whole-life exposure from birth in hexavalent chromium (Cr(VI)) considered a likely carcinogen, 0.38 (mg/kg/day)$^{-1}$ for cadmium (Cd) [17]. There is no oral cancer slope factor in the IRIS database for lead because the EPA does not consider lead to be a carcinogen.

The table also displays the Incremental Lifetime Cancer Risk (ILCR) values for the metals as calculated using equation 2. Incremental Lifetime Cancer Risk (ILCR) is a number that shows how much more likely it is that a person will get cancer over the course of their lifetime if they are exposed to a known or probable carcinogen on a regular basis. Hazard index (HI) obtained from the summation of the various Hazard quotient is as shown on **Table 5** while **Table 6** delineates the outcomes of the four biochemical tests (IMViC - Indole, Methyl Red, Voges-Proskauer, and Citrate) to verify the presence of fecal coliforms and **Table 7** presents the findings of the Most Probable Number (MPN) test performed on the water samples to assess the quantity of fecal coliforms.

Confirmatory Identification of Escherichia coli

Confirmatory biochemical analyses (IMViC tests) were performed to verify the presence of Escherichia coli in water samples collected from Ilaje Local Government Area (LGA), Ondo South Senatorial District. The isolates exhibited characteristic E. coli morphology and biochemical reactions. All isolates were rod-shaped and Gram-negative, showing positive results for indole and methyl red (MR) tests, but negative reactions for citrate utilization and Voges–Proskauer (VP) tests. These results align with the standard biochemical profile of E. coli, thereby confirming its presence in the analyzed water samples.

Table 4. Risk of Cancer.

Metals	CSF [14] (mg/kg-day)$^{-1}$	Incremental Lifetime Cancer Risk (ILCR)
As	32	0.6592
Cr (IV)	0.3	0.01215
Cd	0.38	0.0171
Pb	NA	NA

Note: USEPA IRIS 2025 database does not consider lead to be a carcinogen

Table 5: Hazard Quotient (HQ).

Metals	Reference Dose mg/kg/day	Hazard Index (HQ)
As	6 x 10^{-5}	343.33
Cr	9x 10^{-4}	116.67
Cd	5x 10^{-4}	90
Pb	3 x 10^{-4}	13,876.7
HI		14,426.67

Note: Data are values of Hazard Index (HI) obtained using equation (4). All RfD values are from [14] with the exception of that of lead. The USEPA does not have a current, finalized RfD for lead on its IRIS database as at 2025 hence values used are those cited across selected literature for lead [15,18].

Most Probable Number (MPN) of E. coli

Quantitative assessment of E. coli contamination using the Most Probable Number (MPN) method revealed concentrations ranging from 2 × 10^{6} to 9 × 10^{6} MPN/100 mL, with a mean value of 7 × 10^{6} MPN/100 mL. According to the World Health Organization (WHO) drinking water standard, the permissible limit for E. coli in potable water is 0 MPN/100 mL. The observed values, therefore, indicate severe fecal contamination across all sampled sites. Data represent the minimum and maximum counts (n = 3) obtained for E. coli. Final values are presented as mean ± standard deviation (SD) and were compared with the WHO reference guideline for safe drinking water quality.

DISCUSSION

There is evidence of significant degradation in the water quality across all 10 communities, this is obvious in the key parameters like temperature (>30°C in all), electrical conductivity (EC >500 µS/cm in 8/10 communities), total dissolved solids (TDS >500 ppm in all), turbidity (>5 NTU in all), and total hardness (aesthetic <200 mg/L in 2 communities) surpassing WHO guidelines. This shows widespread thermal and ionic stress likely from human activities, making the water not fit for human consumption and irrigation without treatment as specified in [3,21-23]. The recurrent flaring of hydrocarbon gas in these areas and ongoing oil pollution from spillages may have resulted in significant deviations from the normative values of the indicators. The significant spatial variation suggests that pollution across these communities is localized, because there was no identifiable pattern of increase or decrease either upstream or downstream, but there were random hotspots.

This study's conclusion that the analyzed water had a pH below WHO criteria meant that it was acidic, which is supported by other research findings [23,24]. Due to the progressive deterioration of the rocks and soils, including the disintegration of plaster of Paris and lime, which slowly releases mineral elements into the water bodies, the total dissolved solids (TDS) is high. The higher-than-permissible level of TDS recorded in this research has been reported to have adverse side effects by earlier research findings [4,25]. However, the chloride value in this study is within the WHO standard guideline value of ≤ 250, which agrees with the report in a similar study [26].

Total alkalinity value in this study is at variance with that of [27], who reported higher than safe limit values for total alkalinity in oil-polluted waters of the Niger delta region in Nigeria. The total hardness value in this study is "over range" using the WHO standards [28] hence the water samples were classified as very hard. Hard water requires higher quantity of soap to foam, which is not economically advantageous to the users as they will incur a higher cost for their various soap cleaning processes. The electrical conductivity values in this research are "over range" but aligned with reports of some earlier researchers [12,29] who posited that such water with high values of electrical conductivity is harmful to aquatic and human lives at these high concentrations.

Table 2 revealed the concentration of Pb, Cd, Hg, Al, Cu, Mn, Mb and As to be 145.71, 1.58, 0.008, 0.383, 82.03, 67.52, 0.095 and 0.721, respectively, with all metals having higher than safe levels compared with the WHO standards [22]. The elevated acidity of water samples resulting from mineral leaching in rocks may deteriorate water conduits, consequently elevating the concentrations of some harmful metals beyond prescribed thresholds, leading to adverse effects such as cancer, skin irritations, gastrointestinal disturbances, and diarrhea. Aquatic life is significantly impacted by elevated water acidity resulting from the detrimental impacts of acid rain caused by gas flaring [21,23]. 2.0mg per litre is accepted as safe for copper in potable water [22] to prevent short-term digestive tract problems, the value of 82.03mg/L for copper in this study is far above the permissible WHO limit. This result, however, agrees with the findings of [24] where very high values of copper in drinking water is implicated to cause stomach disorder, vomiting, diarrhea, and headaches.

The lead concentration identified in this study is significantly beyond the acceptable threshold, posing severe health risks to humans and other aquatic organisms, as documented by [31] and [32]. Children under five and fetuses are particularly vulnerable to lead poisoning, as smaller quantities of lead can cause physical and behavioral problems in children more readily than in adults [18,33]. Chronic exposure to cadmium, as indicated in this research, has been associated with renal failure, anemia, and cardiovascular issues, while elevated aluminum levels have been linked to mental disorders, including Alzheimer's disease. The measured concentration of 0.008 mg/L for Hg in this investigation significantly exceeds the WHO limit of 0.001 mg/L for drinking water. Excess mercury is known to damage the brain system, kidneys, and endocrine system, with detrimental effects on the mouth, teeth, and gums [7,36].

Inorganic arsenic (As), with a permissible limit of 0.01 mg/L, contrasts sharply with the mean concentration of 0.721 mg/L observed in this study. This elevated level has been associated with gastrointestinal disturbances, gastroenteritis, and damage to internal organs, resulting in hemorrhage from compromised blood vessels, lethargy, and potential mortality at such concentrations in potable water [37,38]. The consistent amounts of heavy metals surpassing WHO standards, along with minimal variance, indicate widespread pollution, maybe stemming from air deposition or oil drilling, which poses chronic concerns such as neurotoxicity and carcinogenicity [4,21,22]. Overall, our findings indicate the necessity of actions specially tailored for the communities, including targeted monitoring and enforcement of legislation, to mitigate health risks in this vulnerable location. The dosage taken (DT) or Chronic Daily Intake (CDI) of heavy metals by adults, children, and infants on a daily basis from drinking water is as shown in **Table 3** above. According to [14], grown–ups weighing 70kg drink 2 liters of water per day, while children weighing 10kg drink 1 liter per day and infants weighing 5kg drink 0.75 liter per day. This therefore implies that an adult weighing 70kg in any of the communities of study would be consuming 4.163, 0.045, 1.929, 0.0206, 0.386, 0.105, 0.0028, 0.0109, and 0.0002 mg of Pb, Cd, Mn, As, Zn, Cr, Ni, Al, and Hg, respectively, using equation 1. The same equation is used to get the values of heavy metals consumed by children and infants on a daily basis, as recorded on **Table 3**. In communities with higher concentrations of these toxic elements, inhabitants will drink and absorb much more than the estimated values. Although children and babies consume much less quantity of water than adults, the concentrations of the element they ingest is in the order Babies > Children > Adults as revealed in **Table 3**. This same trend has been reported by other researchers [3,37,39].

The risk of cancer was evaluated using equation (3) and CSF values from [14,15] and [17] for arsenic, chromium, and cadmium, respectively, and it is in the order As>Cd>Cr as shown in **Table 4**. Similar results were reported by [18,41] and [42] from Nigeria, India, and South Africa, respectively, while the findings of [34] from Russia are at variance with this result. The Hazard Quotients (HQ) obtained using equation 3 are as documented in **Table 5**, with values in the order Pb>As>Cr>Cd, with all the values being much greater than signalling an exceedance of the non-cancer health guideline by [14], indicating that the source poses a health risk to consumers. In contrast to the results presented in this study, [40] and [42] documented Hazard index values of less than 1 for drinking water at Agbabu water source in Ondo state, Nigeria, and Thulamela municipality, Limpopo province, South Africa. However, the findings of [43] and [44] are consistent with those of this research as they both reported values of HI greater than one (>1) during their evaluations of potable water and irrigation water in the Jamalpur Sadar region of Bangladesh and the Anloga community, Volta Region, Ghana, respectively.

Table 6 reveals the outcomes of IMViC tests that verify the presence of fecal coliforms. The significant presence of *E. coli* in the water samples suggest a lack of proper sanitary conditions in the riverine communities, thereby exposing residents to diseases linked to poor sanitation and unclean environments while **Table 7** presents the findings of the Most Probable Number (MPN) test performed on the water samples to assess the quantity of fecal coliforms revealing a high number of *E.coli* in the water samples contrary to the WHO standard [3,22,28] of zero (0) *E,coli* /100 mL of potable water. The presence of *E. coli* in drinking water, indicating pollution, has been linked to the transmission of several waterborne illnesses, including dysentery, typhoid, and polio. The riverine communities examined in this study lack adequate sanitary infrastructure, as their toilets and washing facilities are situated directly within the water bodies upon which their residences are constructed.

The detection of a significant proportion of *E.coli* in the water samples indicates that the water is polluted with pathogenic germs, rendering it unsuitable for consumption. In earlier studies [45-47], the potential of fecal contamination during the process of collecting and storing water was highlighted, especially in developing countries and communities with inadequate sanitation systems. They also elucidated the detrimental impacts on the health of individuals who consume such water. The study conducted by [48-50] reported that the high burden of diarrhea is mainly attributable to the limited access to improved water and sanitation, and the prevalence of diarrheal diseases in certain areas is consistent with the results obtained in this research, as populations lacking adequate sanitary systems are susceptible to fecal contamination of drinking water by fecal coliforms.

CONCLUSION

The presence of both physical, chemical, and biological pollutants, as observed in the drinking water of the studied areas, has adversely affected the quality of drinking water in the areas. The main heavy metals that were detected in these water samples include cadmium, arsenic, lead, and chromium, while the biological contaminants mainly include *Escherichia coli.* The high concentration of these contaminants is the major factor that could contribute to the high risk of cancer that was obtained from this study. This study, however, suggested proper, effective pollution control and constant sanitation of environments to ensure quality access to good-quality water.

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CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DECLARATION

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted

REFERENCES

1. United Nations. The 2030 Agenda and the Sustainable Development Goals: An opportunity for Latin America and the Caribbean (LC/G.2681-P/Rev.3). Santiago: UN; 2018.
2. Ekere NR, Agbazue VE, Ngang BU, Ihedioha JN. Hydrochemistry and water quality index of groundwater resources in Enugu North District, Enugu, Nigeria. Environ Monit Assess. 2019;191(3):150. https://doi.org/10.1007/s10661-019-7403-6
3. World Health Organization. Drinking-water quality guidelines. 2024. Available from: https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/drinking-water-quality-guidelines
4. Lin L, Yang H, Xu X. Effects of water pollution on human health and disease heterogeneity: a review. Front Environ Sci. 2022;10:880246. https://doi.org/10.3389/fenvs.2022.880246
5. Xu X, Yang H, Li C. Theoretical model and actual characteristics of air pollution affecting health cost: a review. Int J Environ Res Public Health. 2022;19(6):3532. https://doi.org/10.3390/ijerph19063532
6. Merid MW, Alem AZ, Chilot D, Belay DG, Kibret AA, Asratie MH, et al. Impact of access to improved water and sanitation on diarrhea reduction among rural under-five children in low and middle-income countries: a propensity score matched analysis. Trop Med Health. 2023;51:36. https://doi.org/10.1186/s41182-023-00525-9
7. Miller S, Pallan S, Gangji AS, Lukic D, Clase CM. Mercury-associated nephrotic syndrome: a case report and systematic review of the literature. Am J Kidney Dis. 2013;62(1):135–138. https://doi.org/10.1053/j.ajkd.2013.02.359
8. Nayak A, Matta G, Uniyal PD, Kumar A, Kumar P, Pant G. Assessment of potentially toxic elements in groundwater through interpolation, pollution indices, and chemometric techniques in Dehradun, Uttarakhand State. Environ Sci Pollut Res Int. 2024;31:36241–36263. https://doi.org/10.1007/s11356-023-27419-x
9. Chowdhary P, Bharagava RN, Mishra S, Khan N. Role of industries in water scarcity and its adverse effects on environment and human health. In: Environmental Concerns and Sustainable Development. Singapore: Springer; 2020. p.235–256. https://doi.org/10.1007/978-981-13-5889-0_12
10. Wu H, Gai Z, Guo Y, Li Y, Hao Y, Lu ZN. Does environmental pollution inhibit urbanization in China? A new perspective through residents' medical and health costs. Environ Res. 2020;182:109128. https://doi.org/10.1016/j.envres.2020.109128
11. Kristanti RA, Hadibarata T, Syafrudin M, Yilmaz M, Abdullah S. Microbiological contaminants in drinking water: current status and challenges. Water Air Soil Pollut. 2022;233(10):299. https://doi.org/10.1007/s11270-022-05698-3
12. Amalo N, Dibofori O, Owhonda CI, Kufre SU, Amir RS, Mark OO, Prince CM. Spatial and temporal distribution and contamination assessment of heavy metal in Woji Creek. Environ Res Commun. 2019;2(11):115001. https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/7343655
13. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington (DC): APHA; 2023. Available from: https://www.standardmethods.org/
14. United States Environmental Protection Agency (USEPA). Basic information about the Integrated Risk Information System. 2025. Available from: https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system
15. Belew AA, Besha AT, Belete AA. Determination of heavy metals and health risk assessment in drinking water in Jigjiga City, Ethiopia. Discov Environ. 2024;2:41. https://doi.org/10.1007/s44274-024-00071-z
16. World Health Organization. The WHO child growth standards. 2024. Available from: https://www.who.int/toolkits/child-growth-standards
17. U.S. EPA. IRIS toxicological review of hexavalent chromium (interagency science discussion draft). Washington (DC): US EPA; 2024. EPA/635/R-24/104. Available from: https://assessments.epa.gov/risk/document/&deid%3D353296
18. Ugwu CE, Maduka IC, Suru SM, Anakwuo IA. Human health risk assessment of heavy metals in drinking water sources in three senatorial districts of Anambra State, Nigeria. Toxicol Rep. 2022;9:869–875. https://doi.org/10.1016/j.toxrep.2022.04.003
19. Aendo P, Netvichian R, Thiendedsakul P, et al. Carcinogenic risk of Pb, Cd, Ni, and Cr and critical ecological risk of Cd and Cu in soil and groundwater around municipal solid waste open dump in Central Thailand. J Environ Public Health. 2022;2022:3062215. https://doi.org/10.1155/2022/3062215
20. Charkiewicz AE, Omeljaniuk WJ, Nowak K, Garley M, Niklinski J. Cadmium toxicity and health effects—A brief summary. Molecules. 2023;28(18):6620. https://doi.org/10.3390/molecules28186620
21. Teng Y, Li J, Wu J, Lu S, Wang Y, Chen H. Environmental distribution and associated human health risk due to trace elements and organic compounds in soil in Jiangxi Province, China. Ecotoxicol Environ Saf. 2015;122:406–416. https://doi.org/10.1016/j.ecoenv.2015.08.020
22. World Health Organization. Guidelines for drinking-water quality: fourth edition incorporating first & second addenda. Geneva: WHO; 2022. Available from: https://www.who.int/publications/i/item/9789240045064
23. Kumar A, Matta G, Bhatnagar SA. Coherent approach of water quality indices and multivariate statistical models to estimate water quality and pollution source apportionment of River Ganga system in Himalayan region, Uttarakhand, India. Environ Sci Pollut Res Int. 2021;28:42837–42852. https://doi.org/10.1007/s11356-021-13711-1
24. Hansen TH, Thomassen MT, Madsen ML. The effect of drinking water pH on the human gut microbiota and glucose regulation: results of a randomized controlled cross-over intervention. Sci Rep. 2018;8:16626. https://doi.org/10.1038/s41598-018-34761-5
25. Xiao J, Wang L, Deng L, Jin Z. Characteristics, sources, water quality and health risk assessment of trace elements in river water and well water in the Chinese Loess Plateau. Sci Total Environ.

2019;650(Pt 2):2004–2012. https://doi.org/10.1016/j.scitotenv.2018.09.322
26. Hong Y, Zhu Z, Liao W, Yan Z, Feng C, Xu D. Freshwater water-quality criteria for chloride and guidance for revision of the water-quality standard in China. Int J Environ Res Public Health. 2023;20(4):2875. https://doi.org/10.3390/ijerph20042875
27. Maduka O, Ephraim-Emmanuel B. The quality of public sources of drinking water in oil-bearing communities in the Niger Delta region of Nigeria. Int J Environ Stud. 2019;76(5):779–793. https://doi.org/10.1080/00207233.2019.1605364
28. World Health Organization. Drinking water fact sheet. 2022. Available from: https://www.who.int/news-room/fact-sheets/detail/drinking-water
29. Idah SE. A review of impacts of gas flaring on vegetation and water resources in the Niger Delta region of Nigeria. Int J Econ Energy Environ. 2018;2(4):48–55. https://www.sciencepublishinggroup.com/article/10.11648/j.ijeee.20170204.11
30. Chikitsa. Benefits and side effects of drinking water from copper vessel or jug. 2018. Available from: https://www.chikitsa.com/benefits-and-side-effects-of-drinking-water-from-copper-vessel
31. Johnbosco C, Egbueri D, Ayejoto A, Johnson CA. Pollution assessment and estimation of percentages of toxic elements to be removed to make polluted drinking water safe: a case from Nigeria. Tox Rev. 2022;41(1):1–12. https://doi.org/10.1080/15569543.2021.2025401
32. Erik Y, Katarina H, Anna LH, Rasmus P, Maria L, Jukka-Pekka J, Ida-Maja H. Metal and PAH loads from ships and boats, relative to other sources, in the Baltic Sea. Mar Pollut Bull. 2022;182:113904. https://doi.org/10.1016/j.marpolbul.2022.113904
33. Preonty NEJ, Hassan MN, Reza AHM, Ahmed RM, Alom MM, Jannat FT. Pollution and health risk assessment of heavy metals in surface water of the industrial region in Gazipur, Bangladesh. Environ Chem Ecotoxicol. 2025;7:527–538. https://doi.org/10.1016/j.enceco.2025.02.014
34. Postevaya MA, Slukovskii ZI, Dauvalter VA, Bernadskaya DS. Estimation of heavy metal concentrations in the water of urban lakes in the Russian Arctic (Murmansk). Water. 2021;13(22):3267. https://doi.org/10.3390/w13223267
35. Yang Y, Hassan MF, Ali W, Zou H, Liu Z, Ma Y. Effects of cadmium pollution on human health: a narrative review. Atmosphere. 2025;16(2):225. https://doi.org/10.3390/atmos16020225
36. Rohit KV, Mahipal SS, Rajeev K. Mercury contamination in water & its impact on public health. Int J Forensic Sci. 2018;3(2):n.d. Available from: https://www.researchgate.net/publication/331633682_Mercury_Contamination_in_Water_Its_Impact_on_Public_Health
37. Mahipal SS, Rajeev K, Prashant A. Arsenic in water contamination & toxic effect on human health: current scenario of India. J Forensic Sci Crim Invest. 2018;10:55578. https://doi.org/10.19080/JFSCI.2018.10.55578
38. Alidadi H, Tavakoly SS, Zarif G, Oftadeh B, Mohamad T, Shamszade H, Fakhari M. Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran. Environ Health Prev Med. 2019;24:59. https://doi.org/10.1186/s12199-019-0812-x
39. Tracy JW, Guo A, Liang K, Bartram J, Fisher MB. Sources of and solutions to toxic metal and metalloid contamination in small rural drinking water systems: a rapid review. Int J Environ Res Public Health. 2020;17(19):7076. https://doi.org/10.3390/ijerph17197076
40. Onoyima CC, Ibraheem WA. Assessment of water quality of shallow aquifer resources of Agbabu, Ondo State, Nigeria. Chem Search J. 2021;12(2):41–49. https://doi.org/10.30574/chemsearchj.2021.12.2.0108
41. Gursharan K, Ravishankar K, Sunil M, Prafulla KS, Upma V. Ground/drinking water contaminants and cancer incidence: a case study of rural areas of South West Punjab, India. Hum Ecol Risk Assess. 2021;27(1):205–226. https://doi.org/10.1080/10807039.2019.1705145
42. Luvhimbi N, Tshitangano TG, Mabunda JT, et al. Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. Sci Rep. 2022;12:6059. https://doi.org/10.1038/s41598-022-10092-4
43. Zakir HM, Shaila S, Arifa A, Shahinur R. Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. Environ Adv. 2020;2:100005. https://doi.org/10.1016/j.envadv.2020.100005
44. Akoto O, Teku JA, Gasinu D. Chemical characteristics and health hazards of heavy metals in shallow groundwater: case study Anloga community, Volta Region, Ghana. Appl Water Sci. 2019;9:36. https://doi.org/10.1007/s13201-019-0914-z
45. Pande G, Kwesiga B, Bwire G, Kalyebi P, Riolexus A, Matovu JKB. Cholera outbreak caused by drinking contaminated water from a lakeshore water-collection site, Kasese District, southwestern Uganda. PLoS One. 2018;13(1):e0198431. https://doi.org/10.1371/journal.pone.0198431
46. Adesakin TA, Oyewale AT, Bayero U, Mohammed AN, Aduwo IA, Ahmed PZ, et al. Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. Heliyon. 2020;6(8):e04773. https://doi.org/10.1016/j.heliyon.2020.e04773
47. Adeyemo IA. Bacteriological and physicochemical quality of borehole water used for drinking at Olusegun Agagu University of Science and Technology, Okitipupa, Nigeria. Int J Environ Agric Biotech. 2020;5(4):890–897. https://doi.org/10.22161/ijeab.54.7
48. Merid MW, Alem AZ, Chilot D, et al. Impact of access to improved water and sanitation on diarrhea reduction among rural under-five children in low and middle-income countries: propensity score matched analysis. Trop Med Health. 2023;51:36. https://doi.org/10.1186/s41182-023-00525-9
49. Hailu B, Ji-Guo W, Hailu T. Water, sanitation, and hygiene risk factors on prevalence of diarrhea among under-five children in rural Dangila District, Northwest Ethiopia. J Trop Med. 2021;2021:2688500. https://doi.org/10.1155/2021/2688500
50. Ko SH, Sakai H. Water sanitation, hygiene and prevalence of diarrhea in rural areas of the delta region of Myanmar. J Water Health. 2022;20(1):149–156. https://doi.org/10.2166/wh.2021.192